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STRATEGY TO MINIMIZE ENERGETICS CONTAMINATION AT MILITARY TESTING/TRAINING RANGES

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14. ABSTRACT
As a mechanism to maintain the DoD's testing/training capability and mission readiness, the Green Armaments Technology (GAT) Energetics Forensics Initiative (EFI), developed a strategy for 'greening' munitions in order to minimize the contamination on training ranges. First, a comprehensive knowledge base was established with regard to training range contamination as a result of normal use of ammunition by soldiers. The literature and background review included studies regarding fate and transport and toxicology data for the contaminants and the contaminant by-products; characterization of emissions at the firing point and at the impact area; individual range characterization efforts; the role of unexploded ordnance and incomplete detonation of munitions in the contamination; and environmental and health impacts of the contaminants. From the identified root causes of contamination, an Army strategy for "greening" munitions was developed. The strategy was applied to the 155-mm howitzer HE M107 series. Potential alterna-tives for design and manufacturing modifications, which will directly minimize the contamination on training ranges, were identified and research, development, test, and evaluation programs will be developed for the highest priority items.

The EFI provides a mechanism to ensure range sustainability by establishing the nature, extent, and sources of contamination on the ranges, as the basis for a GAT Strategy to "green" munitions, thereby, minimizing potential contamination of ranges. The approach of the EFI will ensure that the Army maintains both the highest level of environmental stewardship of the Nation's resources as well as continued access to facilities vital to military readiness.

15. SUBJECT TERMS
Green Armaments Technology (GAT) Energetics Forensics Initiative (EFI)
Unexploded ordnance (UXO)

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EXECUTIVE SUMMARY

The U.S. Army Armament Research Development and Engineering Center (ARDEC), Picatinny, New Jersey is sponsoring the Green Armaments Technology (GAT) Program. One important goal of the GAT program is to minimize the impacts of energetics contamination on military ranges resulting from testing and training activities. By achieving this goal, the Army will be able to maintain and strengthen its testing/training capability and achieve sustainable ranges. In turn, military readiness can be assured. This report presents the GAT Strategy including the methodology developed to assist the Army in identifying and prioritizing actions necessary to achieve this goal. In addition, the results of demonstrating the methodology on a specific munition item are summarized.

The Department of Defense (DoD) has estimated that more than 1400 sites on 10 million acres of land within the United States and overseas facilities may be contaminated with unexploded ordnance (UXO), explosives, and other hazardous/toxic substances (ref. 1). Much of the contamination resulted from the conduct of essential military training and weapon systems testing that serves the Nation and protects the American people during times of war. In 1997, based on the threat of contamination of the sole source aquifer, the U.S. Environmental Protection Agency (EPA) banned artillery and mortar training at Massachusetts Military Reservation (MMR), setting a precedent and making it clear that the presence of munition constituents and UXO on military ranges can impact military testing and training capability (ref. 2). Consequently, DoD must proactively respond to concerns regarding the impacts to health, environment, and safety of these activities if it is to maintain access to testing and training facilities vital to maintaining military readiness.

The Air Force, Navy, Marine Corps, and Army have each established programs to address the need for sustainable ranges. The Army Environmental Center (AEC) coordinates several of the Army's Sustainable Range Program (SRP) projects, although other organizations support the Army's SRP by conducting research to define the problem of range contamination. As these studies help to define the problem of range contamination, they complement ARDEC's GAT program, which used this information to develop a strategy to minimize the impacts of energetics contamination in the future.

This project addresses one goal of ARDEC's overall GAT program—specifically, minimization of the impacts of energetics contamination on military ranges resulting from the use of medium and large caliber mortar and artillery munitions.

The approach for this project includes: Phase I – Problem Definition, Phase II – GAT Strategy Development, and Phase III – GAT Demonstration. The purpose of the Problem Definition Phase was to establish the state of knowledge and identify data gaps regarding range contamination. Phase I efforts are complete and the results of such are described in the report entitled, "State of Knowledge Regarding Military Range Contamination," dated 30 July 2004 and prepared by FOCIS Associates, Inc. (FOCIS). In the GAT Strategy Phase, the information gathered in the Problem Definition Phase was used to identify root causes of range contamination and to develop a GAT strategy (including a methodology to identify potential Design/Manufacturing changes) leading to minimized range contamination. In the GAT Demonstration Phase, the GAT methodology was demonstrated on a specific munition item. The GAT Strategy and Demonstration are the subjects of this report.

Based on the findings of the Problem Definition Phase I, the GAT Strategy is to minimize range contamination by focusing on modifications to the design and manufacturing stage of the munition life cycle; e.g., maximizing reliability. The GAT Strategy includes a methodology to ensure that a systems engineering approach is consistently applied, and that all impacts are considered, when identifying, prioritizing, and recommending munition design and/or manufacturing changes to minimize range contamination. This methodology was developed to provide guidance and to be general enough that it can be applied to any munition item. Elements of the GAT methodology include:

1. Munition Item Selection – The first step of the GAT methodology is to select a munition item to be analyzed to determine if any opportunities exist to minimize energetics contamination by modifying the Design/Manufacturing Phase of the munition life-cycle.

2. Systems Requirements Review – Once a munition item is selected for analysis, the original systems requirements for the integrated weapon system should be reviewed to ensure that the design rationale is well understood and that opportunities and alternatives identified in the subsequent steps of the GAT methodology do not negatively impact the overall system performance.

3. Potential Alternatives Identification – After the munition item has been selected and the systems requirements for that item have been reviewed, opportunities in the Design/ Manufacturing Phase of the munition life cycle should be examined in order to identify alternatives for minimizing energetics contamination on military ranges.

4. Threshold Criteria Application – Once a list of specific alternatives has been developed, Threshold Criteria should be applied to refine the list of alternatives. The alternatives that pass the Threshold Criteria should move forward in the process for further assessment.

5. Alternative Rating/Ranking – Alternatives that pass the Threshold Criteria should be assessed based on evaluation criteria and associated weighting factors to rate and rank the potential alternatives. The evaluation criteria allow for a comparison between baseline and other alternatives.

6. Alternative Selection – Once consensus is reached regarding the rating of each criterion, the alternatives that appear to have the greatest positive effect with the least amount of negative impacts should be recommended for possible implementation.

After the GAT methodology was reviewed and accepted by ARDEC, it was applied to a specific munition item and modified as necessary. The results of this analysis are presented in the GAT Demonstration Section of this report to assist in the future use/implementation of this methodology. It is expected that the GAT methodology will be periodically updated to respond to lessons learned and to new and emerging opportunity areas. During this process, 33 alternatives were identified. Six alternatives were eliminated because they did not pass the Threshold Criteria. Of the remaining 27 alternatives, seven alternatives were recommended for further consideration. The selected alternatives involve the use of various training rounds and the incorporation of self-destruct fuzes as follows:

- Eliminate the main charge by using the existing technical data package to produce the M804A1 with cast iron

- Increase the use of the M804A1 training round

- Modify the M804A1 training round to increase the signature

- Modify the M107 round with inert filler and a smoke charge in an aluminum liner

- Substitute the main charge with ammonium nitrate filler in a training round
- Substitute the main charge with 2,4,6-Trinitrotoluene (TNT) in a dual use round
- Include a self-destruct feature in the M767 and multi-option fuze for artillery (MOFA) fuzes

It should be noted that the demonstration participants strongly believed that the user community should be consulted prior to recommending implementation of any alternatives.

INTRODUCTION

The ARDEC is sponsoring the GAT Program. One important goal under the GAT program umbrella is to minimize the impacts of energetics contamination on military ranges resulting from testing and training activities. By achieving this goal, the Army will be able to maintain and strengthen its testing/ training capability and achieve sustainable ranges. In turn, military readiness can be assured. This report presents the GAT Strategy and methodology developed to assist the Army in identifying and prioritizing actions necessary to achieve this goal. In addition, the demonstration of the methodology on a specific munition item is summarized.

Background

A 2002 General Accounting Office (GAO) report to Congress states that there are eight encroachment issues that have the potential to impact military testing and training capability. One of those encroachment issues is the presence of UXO and munition constituents on military ranges (ref. 3). The DoD has estimated that more than 1400 sites on 10 million acres of land within the United States and overseas facilities may be contaminated with UXO, explosives, and other hazardous/toxic substances (ref. 1). Much of the contamination resulted from the conduct of essential military training and weapon systems testing that serves the Nation and protects the American people during times of war.

In 1997, based on the threat of contamination of the sole source aquifer, the EPA issued Administrative Order 1-97-1019 through the Safe Drinking Water Act (SDWA), banning artillery and mortar training at Camp Edwards located at the MMR (ref. 2). Consequently, it became clear that DoD must proactively respond to concerns regarding the impacts to health, environment, and safety of these activities if it is to maintain access to testing and training facilities vital to maintaining military readiness.

On 17 August 1999, the U.S. Deputy Secretary of Defense (DEPSECDEF) signed DoD Directive 4715.11, entitled "Environmental and Explosives Safety Management on Department of Defense Active and Inactive Ranges Within the United States," which establishes policy and assigns responsibility for sustainable management of DoD's ranges and protection from explosive hazards. This Directive (updated on 10 May 2004) applies only to operational ranges located within the United States (DoD Directive 4715.12 applies to ranges located outside the United States). As described in this Directive, the Under Secretary of Defense (USD) for Acquisition, Technology, and Logistics is responsible for several actions including but not limited to:

- Developing policy for implementation of the Directive concerning safety, explosives safety, environment, and technology

- Ensuring that research, development, test, and evaluation (RDT&E) programs support sustainable range management

- Coordinating DoD efforts to assess the environmental impacts of munitions use on ranges

- Providing guidance to prevent or mitigate the spread of munitions constituents off the range

In addition, based on DoD Directive 4715.11, each DoD component must complete several actions including, but not limited to compiling an updated list of ranges, assessing environmental impacts of munitions on ranges, and developing and updating (at least every 5 years) sustainable range management plans. The DoD ranges are required to maintain permanent records of expended munitions including information such as type, quantity, location, and estimated dud rates (ref. 4). This DoD Directive was followed by DoD Directive 3200.15 on 10 January 2003, which expanded on the policies and responsibilities for the sustainment of testing and training ranges (ref. 5).

In addition, on 20 March 2002, the DEPSECDEF released a memorandum entitled, "Force Readiness and the DoD Munitions Action Plan," which implemented the Munitions Action Plan (MAP), dated November 2001. The MAP, which applies only to conventional military munitions, was developed by DoD's Operational and Environmental Executive Steering Committee for Munitions to "identify actions that will help maintain the combat readiness of our armed forces by enhancing explosives safety and improving environmental stewardship across the complete munition life cycle." Three of the MAP's 29 objectives, which are particularly relevant to range contamination, are (ref. 6):

- "Develop/implement munitions acquisition Strategy or plan that minimizes or eliminates undesirable environmental and explosive safety impacts throughout the life cycle

- "Achieve better understanding of munitions-related environmental impacts and improved UXO-related technologies

- "Assess environmental effects on operations ranges"

Furthermore, the USD for Personnel and Readiness released a memorandum on 26 June 2003 entitled, "Guidance for Fiscal Year (FY) 2006-2011 Sustainable Ranges Programs," which described the need to assess potential hazards from off-range migration of munitions constituents (ref. 7).

The Air Force, Navy, Marine Corps, and Army have each established programs to address the need for sustainable ranges. For example, the U.S. Air Force Center for Environmental Excellence (AFCEE) considers range sustainment to be the "new environmental pillar" and established the Range Support Unit in August 2000. The Range Support Unit personnel provide support and expertise to range managers to help them address environmental issues impacting sustainable ranges such as range residue management and explosive safety (ref. 8).

The Navy's Commander Fleet Forces Command and Commander, Pacific Fleet jointly developed the Tactical Training Theater Assessment and Planning (TAP) program. The TAP program includes five primary products (refs. 9 to 11):

- Range Complex Management Plans (RCMP) will define the capabilities necessary to maintain, improve, and modernize training areas

- Environmental planning documents including comprehensive Environmental Impact Statements, will identify potential environmental consequences of training

- Operational range clearance element includes routine clearance and disposal and satisfies the DoD Directive 4715.11

- Marine species density data will determine the population density in specific areas and provide data in a centralized location

- Range Sustainability Environmental Program Assessments (RSEPA) is intended to provide a "consistent and defensible approach for assessing the environmental condition of land-based operational ranges (excluding small-arms ranges)"

The Chief of Naval Operations Environmental Readiness Division (N45) published the RSEPA Policy Implementation Manual in December 2003 (ref. 12). The RSEPA program involves three steps:

- Range condition assessment

- Comprehensive range evaluation

- Comprehensive range evaluation

The Naval Facilities Engineering Service Center is supporting the RSEPA program with a project to compile relevant information as well as a project to study the importance of UXO in marine environments as sources of contamination.

The Marine Corps developed the Range Environmental Vulnerability Assessment (REVA) program to ensure range sustainability. As with the Navy's TAP program, the goal of the REVA program is to define the activities conducted at each range and determine the potential environmental impacts. There are four phases in the REVA program (refs.13 and 14):

- Baseline range and training area assessments

- Groundwater and surface water fate and transport modeling

- Data gap analysis and confirmation sampling

- Long-term program execution

Headquarters Department of the Army (HQDA) Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS or G-3) initiated the Army's SRP. The objective of the SRP is to "maximize the capability, availability, and accessibility of ranges and land to support doctrinal training and testing requirements." There are three primary steps (ref. 15):

- Develop and maintain data on ranges
- Integrate range modernization, facilities and installation management, explosives safety, and environment into range operations
- Conduct an outreach campaign to educate the public on testing/training requirements

The Army Range Sustainment Integration Council (ARSIC) was tasked to develop the Sustainable Range Program Plan (SRPP) to integrate the G-3's core SRP programs: Range and Training Land Program (RTLP) and Integrated Training Area Management (ITAM). This plan, released by the G-3 on 6 August 2003, provides procedures for HQDA, Major Command (MACOM), Installation Management Agency (IMA), and installation level SRP implementation (ref. 16).

The SRP addresses all elements of encroachment that could limit military range access and reduce readiness. Under direction from the Assistant Chief of Staff for Installation Management (ACSIM), the Office of the Director Environmental Programs (ODEP) manages the elements of the SRP that address environmental issues, such as range contamination. The ACSIM also established a General Officer Steering committee, which tasked the AEC to develop the necessary data to reduce the potential liability of range contamination (ref. 17).

The AEC coordinates several sustainable range projects, which include small arms range projects as well as range and munition projects. Besides AEC, other organizations support the Army's SRP by conducting research to provide data to define the problem of range contamination. The Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) Laboratories, the Army's Environmental Quality Technology (EQT) program, the Strategic Environmental Research and Development Program (SERDP), and the Center for Health Promotion and Preventive Medicine (CHPPM) are examples of key research organizations that are currently involved in such studies. As these studies help to define the problem of range contamination, they will complement ARDEC's GAT program, which will use this information to develop a strategy to minimize the impacts of energetics contamination in the future.

Objective and Scope

To address the need for sustainable ranges, ARDEC tasked FOCIS to develop a strategy to reduce the environmental impacts of live fire testing and training by "greening" the munitions used on military ranges.

Specifically, the scope of the project includes energetics contamination (as opposed to heavy metal or other contamination) on military testing and training ranges and does not include the full range of encroachment issues; e.g., noise, urban sprawl, threatened and endangered species. The munitions of most interest are high explosive (HE), medium (40 to 60 mm), and large (>60 mm) caliber mortar and artillery rounds. Small caliber munitions, rockets, missiles, and depleted uranium munitions have been excluded from the scope of this project.

As shown in figure 1, the three phases of the life cycle for a munition ultimately used for testing or training are defined for the purposes of this project as:

- The Design/Manufacturing Phase of the munition life cycle includes the design, manufacture, load/assemble/pack (LAP), and storage of munitions

- The Testing/Training Phase begins when the munitions are transferred to the Army installations for testing or training and ends after each round has been fired

- The Range Maintenance Phase of the munition life cycle covers procedures to clear operational ranges of UXO or to maintain ranges after testing or training exercises have been conducted

A comprehensive strategy would encompass all three phases of the munition life cycle. However, since ARDEC's goal in this project is to promote "Green Armaments," the GAT Strategy focuses on the Design/Manufacturing Phase of the munition life cycle. (Although it is not part of the scope of this project, it should be noted that changes in the testing/training and range maintenance Phases of the munition life cycle, such as modifying training range procedures or improving remediation technologies, may also minimize range contamination and contribute to the goal of sustainable ranges.)

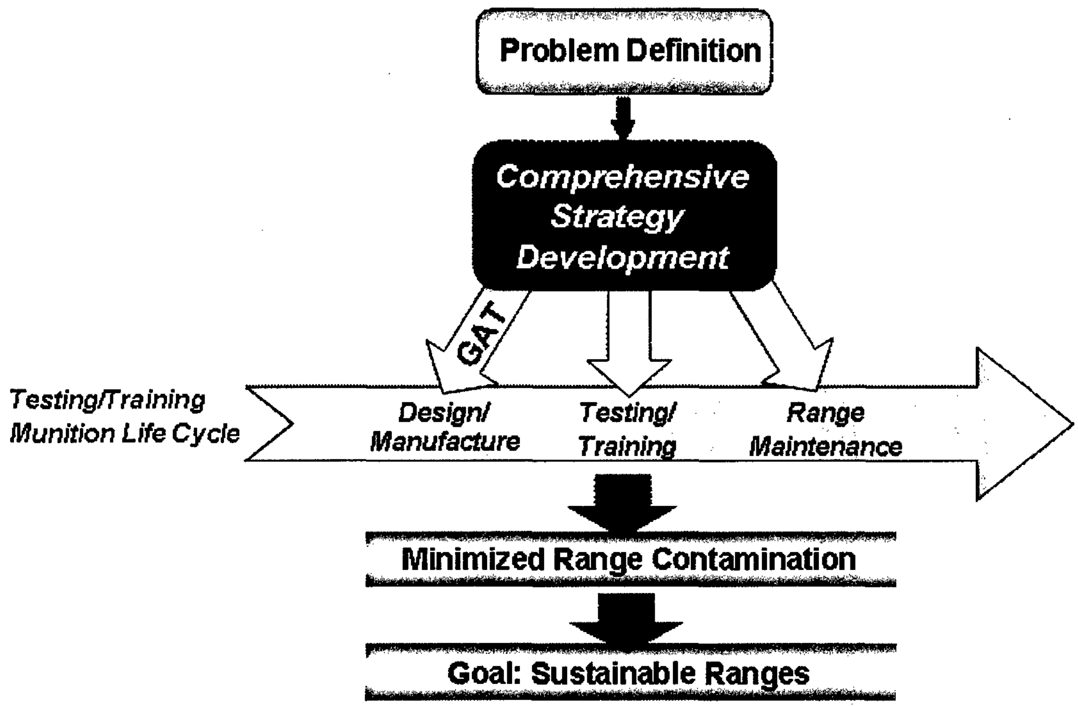


Figure 1
ARDEC's approach to range sustainability focuses on design/manufacture

Approach

The approach for this project included: Phase I – Problem Definition, Phase II – GAT Strategy Development, and Phase III - GAT Demonstration. The purpose of the Problem Definition Phase was to establish the state of knowledge and identify data gaps regarding range contamination. This step was critical for the development of a GAT Strategy because the nature, extent, and source of contamination must be well understood in order for ARDEC to make an informed decision about which changes will minimize the impacts of range contamination. Phase I of the project involved a review of over 450 documents identified during a focused literature search, site visits, and telephone interviews with DoD organizations involved in research related to range contamination. Furthermore, ARDEC, with the support of FOCIS, sponsored a Green Armaments Technology Workshop in Cambridge, Massachusetts on 18 to 20 November 2003. The findings from the Problem Definition Phase were presented in two separate reports prepared by FOCIS: "Green Armaments Technology Workshop Summary Report," dated 16 January 2004 and "State of Knowledge Regarding Military Range Contamination," dated 30 July 2004.

In the GAT Strategy Development Phase, the information gathered in Phase I was used to identify root causes of range contamination and to develop a GAT Strategy (including a methodology to identify alternatives) leading to minimized range contamination. The GAT Strategy and the methodology for achieving this goal are presented in next in this report.

In the GAT Demonstration Phase, the GAT methodology was demonstrated with a specific munition item. This demonstration is described in the GAT Demonstration section of this report.

GAT STRATEGY

Based on the findings of the Problem Definition Phase, the GAT Strategy is to minimize range contamination by focusing on modifications to the design and manufacture stage of the munition life cycle; e.g., maximizing reliability. The GAT Strategy includes a methodology to ensure that a system engineering approach is consistently applied and that all impacts are considered when identifying, prioritizing, and recommending munition design and/or manufacturing changes to minimize range contamination. This methodology was developed to provide guidance and to be general enough that it can be applied to any munition item. Elements of the GAT methodology include:

1. Munition Item Selection
2. System Requirements Review
3. Potential Alternatives Identification
4. Threshold Criteria Application
5. Alternatives Rating/Ranking
6. Alternatives Selection

Select Munition Item for Analysis

The first step of the GAT methodology is to select a munition item to be analyzed for alternatives to minimize energetics contamination by modifying the Design/Manufacturing Phase of the munition life-cycle. The scope of this project includes medium and large caliber HE munition items. According to ARDEC, medium caliber is defined as 40- to 60-mm rounds. It follows that large caliber rounds would be greater than 60 mm and therefore, the potential list of munition items includes:

- Mines
- 40-mm grenades

- 60-mm mortar rounds
- 81-mm mortar rounds
- 120-mm mortar rounds
- 105-mm artillery rounds
- 155-mm artillery rounds

Selecting a specific munition item for analysis will require consideration of the following:

- Known concerns with contamination resulting from a specific munition item
- Projected training use in the near future; e.g., in the next 5 years
- Mass of HE per round
- Type and environmental impact of HE
- Number of active training ranges and type of rounds used at each range
- Acreage of impact area at each range
- Dud and low order detonation rate per fuze and per round
- Age and storage conditions of fuzes and rounds
- Production status; e.g., obsolete, out of production, active
- Number of items currently in the stockpile
- Number of fuzes per munition type

Review Systems Requirements

Once a munition item is selected for analysis, the original systems requirements for the integrated weapon system should be reviewed to ensure that the design rationale is well understood and that opportunities and alternatives identified in the subsequent steps of the GAT methodology do not negatively impact the system performance. This is accomplished by examining the systems engineering flow down to become familiar with the decision-making process undertaken when the munition was first developed.

A systems engineering flow down is the process by which the systems engineer establishes, partitions, and allocates requirements from the overall weapon system to the various components. It is also the process by which the component engineer allocates and develops the individual elements to the sub-components. How each part is expected to contribute to this integrated result will influence the design of the end item. For example, on an aircraft there is a total mass requirement for the finished design, say 5000 lbs. The flow down would allocate the total mass to the various systems based on heritage design, experience, and analysis. The airframe may account for 2000 lbs, fuel may account for 1000 lbs, avionics (including wiring) may account for 1000 lbs, and the engine would be allocated the remaining 1000 lbs. The avionics would then be allocated to the various systems; e.g., 200 lbs for wire and cable, 100 lbs for the radar, 100 lbs for the flight control, 75 lbs for the cockpit displays and controls. This process would be repeated for all the requirements: mass, power, volume, cost, etc. Obviously, there are many trade-offs to be considered. If more mass is allocated to fuel, you could have longer range, but lose performance. The result of all these trade-offs, compromises, and flow downs ends up in the critical item development specifications at both the system level and the various components.

A systems requirement for a munition may be to create a certain fragmentation pattern as the munition functions over the target. Fragmentation patterns can be accomplished in part by the HE fill and in part by the munition case. If the munition case is expected to support more of the requirement, thereby, reducing the amount of HE, the munition case may need to be stressed on the inner surface to induce fragmentation or be hardened to enhance brittle breakup. If the HE fill is expected to contribute more of the requirement, it may be necessary to use an initiation sequence to wave shape the resulting shock energy to cause a fragmentation of non-stress raised case material. In some situations, changing the HE fill material to a lower energy, yet more environmentally benign alternative, may not look attractive since you can not generate enough fragmentation energy, yet, by wave shaping the material or scoring the case, such a change could be made fully compliant to the systems requirements. Additionally, it should be noted that the munition is only a part of the weapon system and any change to the munition must be "flowed up" to the fully integrated weapon system to ensure that mission objectives are fully supported.

Reviewing systems requirements will influence the identification and focus of GAT opportunities and alternatives because it allows consideration of the ultimate impact on the deployed systems. By reviewing systems engineering baseline and rationale, the munition design will be better understood so that recommendations for changes can be responsive to requirements and recommendations that might otherwise be overlooked can be developed. Additionally, and of equal importance, changes that could adversely impact the weapon systems performance are disregarded early in the process avoiding latent, and potentially costly, impacts to the inventory.

Identify Potential Alternatives

After the munition item has been selected and the systems requirements for that item have been reviewed, opportunities in the Design/Manufacturing Phase of the munition life cycle should be examined in order to identify alternatives for minimizing energetics contamination on military ranges. For the purposes of this project, the boundaries of Design/Manufacturing Phase of the munition life cycle have been defined to include the design, manufacture, LAP, and storage of munitions prior to shipment to installations for use. (Note: The testing/training and range maintenance Phases of the munition life cycle are not included in the scope of this project.) Opportunities to minimize range contamination can be organized into five areas:

1. Eliminate energetics
2. Substitute energetics
3. Reduce energetics

4. Maximize reliability

5. Minimize environmental impact

The relationship between the areas of opportunities and the Design/Manufacture Life Cycle Phase is illustrated in table 1. In addition, targets within each area of opportunity are presented.

Eliminate Energetics

The process of identifying alternatives begins with opportunities to eliminate energetics. Ideally, the design of the munition could be modified to eliminate energetics from the munition in part or altogether. Eliminating energetics would be the most effective means of minimizing range contamination because the energetics would never come into contact with the environment. As shown in tables 1 and 2, only design changes are likely in this category. In order to ensure all opportunities are considered, the three energetic components of a munition (propellant, fuze, and main charge) are targeted separately.

Table 1
Areas of opportunities and targets for minimizing range contamination

	Area of opportunity				
	1. Eliminate energetics ➤	2. Substitute energetics ➤	3. Reduce energetics ➤	4. Maximize reliability ➤	5. Minimize environmental impact
			Target		
Design	A. Propellant B. Fuze C. Main charge	A. Propellant B. Fuze C. Main charge	A. Propellant B. Fuze C. Main charge	A. Propellant B. Fuze C. Main charge D. Integrated platform E. Packaging	A. Prevent exposure
Manufacture				F. Propellant G. Fuze H. Main charge I. Hardware/ metal parts	
LAP				J. Facilities K. Operations	
Storage				L. Age & climate	

Table 2
Opportunities to eliminate energetics

Opportunity	Target		
	Propellant	Fuze	Main charge
Alternative technology – Alternative non-energetic technologies have the potential to eliminate propellant or energetic components in the fuze train while still achieving the function currently accomplished by the energetics.	√	√	
Non-energetic material – Training rounds with non-energetic material in place of the main charge explosive may reduce their environmental impact while providing a realistic training experience through the launch sequence.			√

Substitute Energetics

Next, if energetics must be used, then substituting the current energetic with another energetic that provides the same or better performance, but has a lesser environmental impact when deposited on a range, should be considered. It should be noted that environmental impact can be based on toxicity, exposure, or other factors, so a consensus should be reached on the impacts of each explosive prior to recommending a substitution. In this category, different energetics could be employed. In order to ensure all opportunities are considered, the three energetic components of a munition (propellant, fuze, and main charge) are targeted separately. As shown in tables 1 and 3, only design changes are possible in this category.

Table 3
Opportunities to substitute energetics

Opportunity	Target		
	Propellant	Fuze	Main charge
More environmentally acceptable energetics – Modifying the munition design to replace currently used propellants, fuze components, or main charge explosives with greener formulations can reduce the environmental impact on energetic residue on testing/training ranges.	√	√	√

Reduce Energetics

In addition to substitution, the amount of energetic used in each munition could be reduced to achieve the same performance, but still minimize range contamination. In order to ensure all opportunities are considered, the three energetic components of a munition (propellant, fuze, and main charge) are targeted separately. As shown in tables 1 and 4, only design changes are likely in this category.

Table 4
Opportunities to reduce energetics

Opportunity	Target		
	Propellant	Fuze	Main charge
Optimization of quantity required – Determining the optimal (i.e., minimal) quantity of propellant, fuze energetics, or main charge explosive required to achieve the desired performance may allow for the quantity of energetic to be reduced.	√	√	√
Higher output energetics– Use of higher output propellants, fuze energetics, and main charge explosives may reduce the quantity of energetic required.	√	√	√
Alternative technology – Approaches that improved reaction efficiency can reduce the quantity of propellant or main charge explosive required. Technologies (e.g., electronics, higher reliability initiators, or multi-point initiators) used in place of energetics in the fuze train can reduce the quantity of energetics required.	√	√	√
Binders – If the propellant or main charge explosive contains a binder, the use of an energetic binder may allow for a reduction in the total quantity of energetic required to achieve the output. While contributing to the energetic output, energetic binders may improve the detonation velocity through the material, obtaining a more precise output.	√		√

Maximize Reliability

After possible opportunities are identified to eliminate, substitute, or reduce the energetic in the munition, the GAT methodology addresses design, manufacturing, LAP, and storage changes that could be made to increase the functional reliability of each round. This step is based on the finding that low order detonations and, to a lesser extent, duds are the primary contributors to energetics contamination on military ranges. Increasing reliability of the munition to reduce low order detonations and duds can minimize range contamination. As shown in table 1, changes can be considered in design, manufacture, LAP, and storage to maximize the reliability of the munition. Table 5 presents the opportunities to maximize reliability through design changes. In order to ensure all opportunities are considered, the three energetic components of a munition (propellant, fuze, and main charge), as well as the integrated platform and packaging, are targeted separately. Table 6 presents the opportunities to maximize reliability through changes in manufacturing procedures. In order to ensure all opportunities are considered, the three energetic components of a munition (propellant, fuze, and main charge) and the hardware/metal parts of the munition are targeted separately. Table 7 presents the opportunities to maximize reliability through changes in LAP procedures. In order to ensure all opportunities are considered, LAP facilities and operations are targeted separately. Table 8 presents the opportunities to maximize reliability through changes in storage.

Minimize Environmental Impacts

Finally, assuming that low order detonations and duds might still occur even if opportunities in the first four categories are implemented, the GAT methodology addresses those design changes that can be made to minimize the environmental impacts of low order detonations and duds. As shown in tables 1 and 9, only design changes are likely in this category.

The identification of potential alternatives is focused on these five areas of opportunities. For illustrative purposes, examples of potential alternatives for each of the opportunities and targets are presented in table 10. This process involves not only identifying, devising, and formulating specific alternatives, but also researching and describing all of the implications of implementing this alternative. These implications will be considered during application of threshold and evaluation criteria discussed next.

Table 5
Opportunities to maximize reliability through design

Opportunity	Target				
	Propellant	Fuze	Main charge	Integrated platform	[illegible]
Formulation/configuration – Propellant formulations that demonstrate improved combustion efficiency and main charge explosive formulations that provide a more uniform density can result in improved performance and reliability. Using newly developed, more-reliable fuzes or reconfiguring the fuze may increase reliability.	√	√	√		
Coatings – Coating applied to propellant may provide for increased reliability due to the elimination of contamination from moisture or other degrading materials. Propellant coatings can support flow and provide burn enhancement. In addition, propellant coatings can preserve homogeneity of the propellant mix. Explosive coatings may be used to facilitate processing and/or add desensitizers to the charge. Coatings can be used as density modifiers to enhance densification and achieve uniform density across the charge.	√		√		
Binders – If the propellant or main charge explosive contains a binder, the use of an energetic binder may improve reliability by decreasing dead spots in the energetic matrix.	√		√		
Performance optimization - Analysis of data that reflect the actual performance of the munition in the field will allow for the identification of issues that may negatively affect reliability of the munition. Resolution of the issues may result in the optimization of the munition's performance and reliability.		√		√	
Alternative technology - Alternative technologies, such as electronics, to replace the pyrotechnic functions within the fuze may improve reliability by permitting testing before use. Alternative technologies may allow for improved reliability through a reduction in the number of critical interfaces.		√			
Redundancy - Functional reliability of the fuze may be greatly enhanced by the incorporation of redundancy in the fuze function.		√			
Protection from contamination and damage - Adequate protection of the fuze energetics from contamination by moisture or volatiles may enhance the performance and reliability of the fuze. Eliminating contact and hidden shock damage and providing adequate encapsulation from the environment with packaging can contribute to reliability.		√			√
Materials of construction - Material incompatibilities may accelerate decomposition or degradation of energetic materials and compromise reliability. For example, outgassing from elastomeric seals may result in degradation of the booster pellet.				√	
Energetic interfaces - The characteristics of energetic interfaces (e.g., gap distance, type and grain structure of metal discs that separate the energetics, differences in velocity of detonation, and geometry) may impact the overall reliability of the explosive train.				√	
Variability control - Product variability can threaten reliability. The design of the product can affect this variability since the design specifications may dictate the types of processes to be used in its manufacture. For example, the use of a glued joint may introduce a higher degree of variability in the product than a more repeatable mechanical joint.				√	
Prediction of performance - The capability to predict the potential for a munition to malfunction would allow the user to remove the item from the stockpile prior to being fired on a range.					√

Table 6
Opportunities to maximize reliability through manufacturing

Opportunity	Target: Propellant	Target: Fuze	Target: Main charge	Target: Hardware/ metal parts
Production demand fluctuations - Some production processes may be impacted by starts, stops, and production rate variations as a function of demand. Such fluctuations may threaten product reliability. Product demand should be managed so as to minimize variation and maximize reliability.	√	√	√	√
Production discontinuities – Like production demand fluctuations, shift changes and other discontinuities may impact component or munition variability and reliability.	√	√	√	√
Product movement - Movement of product from one workstation to another can increase its vulnerability to contamination or damage and thereby threaten its reliability.	√	√	√	√
Variability analysis - The production process should be analyzed to minimize variance that impacts product reliability. For a given process, C_{pk}, a statistical measure of manufacturing process variability, should be 1.33 or greater to ensure product reliability.	√	√	√	√
Processing of raw materials - Raw materials should be processed in ways that minimize volatiles and moisture, the presence of which can impact reliability. A loss in reliability can be caused by volatiles in the raw materials that desensitize the energetic. Solvents present in the bulk energetic can result in recrystallization and desensitization of energetics. After drying, and prior to sealing, powders are susceptible to moisture intrusion resulting in desensitization and loss of reliability of the energetic. A uniform density will ensure a uniform performance output and uniform sensitivity at the energetic interfaces.	√		√	
Raw material quality - Variability in raw materials for the propellant and explosive main charge as well as variability in fuze components can affect the quality, and thus the reliability, of the final product.	√	√	√	√
Production methods – The way propellant and explosive main charges are processed will affect product variability and, in turn, have an impact on reliability.	√		√	
Personnel Turnover – Interrupted or sporadic production demand can result in employee turnover. Furthermore, the use of union workers may result in different crews being assigned to work on the production line each week.	√	√	√	√
Protection from contamination and damage - Contamination of fuze train interfaces during the manufacturing process can negatively affect their performance and munition reliability. Contaminants might include skin oils, workstation items, and packaging residues. Contamination of metal parts and other hardware (e.g., that resulting from packaging remnants and shipping/assembly aides, handling and cleaning residues, and airborne contaminants such as compressed air oil mist) can contribute to material incompatibility and other detrimental effects that can impact reliability.		√		√
Adhesives - Issues associated with the use of glues or adhesives include the potential for contamination of critical interfaces and the quality of application as driven by pot life of the adhesive, surface preparation, and under- or over-application.		√		
Static control - The presence of static electricity in the manufacturing process may have a negative impact on the electronic and energetic components of the fuze and thereby affect munition reliability. Potential problems include premature functioning of the electro-explosive device, desensitization of the energetic at the hot bridge wire element, degradation of interface reliability, and damage to electronic elements within the electronic module in a fuze.		√		
Validation of fuze - Typically, the fuze is a blind assembly and an inability to adequately verify the presence, quantity, order, and orientation of all fuze components may affect the reliability of the fuze.		√		
Compatibility with energetic - All materials used in the manufacture of metal parts and other hardware must be compatible with the energetic to prevent its degradation over time.				√

Table 7
Opportunities to maximize reliability through LAP

Opportunity	Target	
	Facilities	Operations
Housekeeping - Cleanliness and order can minimize the potential for contamination and maximize visual control. For example, good housekeeping will provide a clear line-of-sight to critical processes and allow for increased operator awareness.	√	
Environmental Controls - Adequate control of heating, ventilation, and air conditioning (HVAC) and other workplace environmental characteristics can help to ensure product quality and consistency and eliminate potential contaminants such as dust and moisture.	√	
Loading processes - Loading and consolidating processes determine the density and uniformity of the energetic, which, in turn, influences the output and sensitivity of the munition. Uniform density is important to achieve consistent performance and reliability.		√
Optimization of process steps - Unnecessary process steps increase the vulnerability of the munition to contamination.		√
Automation - Implementing automation may increase product reliability due to the elimination of human variability.		√
Process flow - The order of assembly can influence the product quality and consistency and, hence, reliability. For example, the order of assembly may affect the stack-up of tolerances.		√
Quality assurance - Quality should be verified at several stages in the LAP process in order to ensure product quality and performance.		√

Table 8
Opportunities to maximize reliability through storage

Opportunity	Target
	Storage
Age – The age of a munition item can impact its reliability due to possible degradation of key components.	√
Storage conditions – The climate and handling to which a munition is subjected during storage can affect its performance and reliability.	√

Table 9
Opportunities to minimize environmental impacts

Opportunity	Target: Prevent Exposure
Isolation of energetics from environment – If a round is incompletely detonated, isolation of the energetic may minimize the resulting contamination.	√
Location of incompletely detonated munitions for removal – If a round is incompletely detonated, improved methods for recording and locating the round will facilitate its removal from the range and, in turn, remove the potential for further contamination.	√
Prevention of sympathetic detonations – Exposure of energetic to the environment may be less if a fired munition results in a dud rather than a low order detonation. Preventing a low order detonation occurring from sympathetic detonation of a dud may reduce the potential for energetic contamination.	√

Table 10
Examples of alternatives for each opportunity

Target	Opportunity	Example alternative
Area I: Eliminate energetics		
A. Propellant	1. Alternative technology	• Electromagnetic gun technology • Hydrogen combustion
B. Fuze	1. Alternative technology	• Electronics to replace pyrotechnic timing functions in the fuze train
C. Main charge	1. Non-energetic material	• Concrete to replace energetics in training rounds • Instrumentation packages installed in place of main charge for training feedback via data telemetry
Area II: Substitute energetics		
A. Propellant	1. More environmentally acceptable energetics	• PAP7993 (Populseur d'Appoint á Poudre) solid propellant, nitrocellulose-based with more environmentally acceptable plasticizers than used in other propellants • Novel energetic thermoplastic elastomers (TPE)-based propellants in advanced, layered geometries, that incorporate high-energy fillers
B. Fuze	1. More environmentally acceptable energetics	• Hexanitrostilbene (HNS) used in other energetic transfer applications such as mild detonating fuze (MDF) transfer leads • PBXN-301, a pentaerythritol tetranitrate (PETN)-based plasticized and waterproof HE that resists erosion and migration in the environment
C. Main charge	1. More environmentally acceptable energetics	• Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)-based charges in place of hexahydro-1,3,5-trinitro-1,3,5 (RDX) • PBXN-9, a plasticized and waterproof HE used as an insensitive munition bomb fill that resists erosion and migration in the environment • Octianit, a novel high-output energetic
Area III: Reduce energetics		
A. Propellant	1. Optimization of quantity required	• Computer modeling to optimize (i.e., reduce) quantity of propellant for needed output
	2. Higher output energetics	• Propellant systems incorporating 1,5-diazido-3-nitraza pentane (DANPE) and a HE such as 1,1,3 trinitroazetidine (TNAZ) or CL-20 that theoretically possess approximately 25% greater impetus than currently fielded gun propellant systems
	3. Alternative technology	• Nanometallics (e.g., aluminum) blended into the propellant to enhance the burn and resulting output • Advanced hydrocarbon fuel-based propellants incorporating strained-ring hydrocarbons such as Quadricyclane, Bi-cyclopropylidine, or Octadiyne
	4. Binders	• Glycidal azide polymer (GAP), an energetic binder

Table 10
(continued)

Target	Opportunity	Example alternative
Area III: Reduce energetics (continued)		
B. Fuze	1. Optimization of quantity required	• Hydrocode-based models to optimize performance per unit of energetics in the fuze as a means to reduce total energetic quantity required • Computer modeling to reduce energetic content by identifying where energetics are not contributing to performance
	2. Higher output energetics	• Plasticized and fuze-compatible energetics, such as PBXN-5 (HMX-Viton), to improve explosive output
	3. Alternative technology	• High-acceleration rated electronic timers to replace energetic transfer leads • High reliability single initiators to replace dual initiators and Precision Initiation Couplers (PICs)
C. Main charge	1. Optimization of quantity required	• Computer modeling to identify unproductive energetic content (e.g., comers and detonation run-up areas) that can be eliminated or filled with non-energetic ballast
	2. Higher output energetics	• HMX-based higher output energetics • Octanit, a novel high-output energetic
	3. Alternative technology	• Enhanced (multipoint/peripheral) initiation to yield more output per unit energetic (such as that used in the Sidewinder warhead) • Shape output charge to gain directionality and reduce energetic required for desired output [such as that in the Penetrating Augmented Munition (PAM) warhead]
	4. Binders	• bis-(2-fluoro-2,2-dinitroethyl)formal (FEFO), an energetic binder • GAP, an energetic binder
Area IV: Maximize reliability		
A. Design of propellant	1. Formulation/configuration	• Use of nanometallics to enhance burn rate and impetus
	2. Coatings	• AKARDIT II to enhance performance • Ethyl centralite to enhance performance
	3. Binders	• FEFO, an energetic binder • GAP, an energetic binder
B. Design of fuze	1. Formulation/configuration	• Reduction of the number of critical interfaces in the fuze train • Addition of sensitizer to booster pellet at interface with fuze lead to increase reliability • Reduce fuze length-to-diameter ratio to minimize blind assembly during manufacture and to minimize round failure due to intra-munition shock effects prior to main charge detonation
	2. Performance optimization	• Review of actual performance data versus design data to provide a realistic measure of the degree of reliability and identify areas to focus on for improvements
	3. Alternative technology	• Microprocessor-based logic and radio frequency (RF) technologies (such as those used in the MOFA) to increase fuze reliability • Newer fuze technology with enhanced arming and firing capability (e.g., setback rotation) and other enhancements based on the latest operational feedback
	4. Redundancy	• Identification of highest risk areas where redundancy would improve reliability • Back-up self-destruct timer to detonate round in the event of dud • Alternative initiation (e.g., point-detonating fuze) to backup proximity fuze failure • Dual (block-redundant) fuzing
	5. Protection from contamination and damage	• Laser welding to provide hermetic sealing to isolate critical elements of the fuze train • Projection welding to hermetically seal to isolate critical elements of the fuze train

Table 10
(continued)

Area IV: Maximize reliability (continued)		
Target	Opportunity	Example alternative
C. Design of main charge	1. Formulation/configuration	• Plasticized energetics, such as plastic-bonded explosive (PBX) formulations, with enhanced stability and reliability • Main charge sub-assemblies that can be processed external to the round and coated for containment and environmental stability • Shaping of main charge (e.g., PAM warhead) for optimization of performance.
	2. Coatings	• Polymer coating to enhance densification and consistency of density across the charge
	3. Binders	• Energetic binders (e.g. FEFO or GAP) to reinforce the principal HE output and improve performance and reliability of munition functioning
D. Design of integrated platform	1. Performance optimization	• Computational modeling of structural design throughout the munition storage and operating regime to ensure functional reliability • Hydrocode-type modeling for dynamic analysis of energetic events to optimize design of key interfaces and critical output functionality • Development and use of models to predict functional performance and reliability • Statistical Process Control (SPC) charting to identify process disruptions, identify their root causes, and make corrective actions that make the process more predictable and reliable
	2. Materials of construction	• Elastomeric seals that will not offgas and degrade the booster pellet • Cleaning materials compatibility with energetics
	3. Energetic interfaces	• Optimization of interface characteristics (e.g., air gaps versus intimate contact, velocity-of-detonation matching, etc.) for specific energetics involved to maximize reliability
	4. Variability control	• Establishment of a C_{pk} quality system to insure alignment of the munition design with the processes used to produce that munition • Reduction of variability in target areas identified by C_{pk} • Replacement of component sets that are bind-assembled inside the round with those that can be assembled externally and installed as a sub-assembly with positive visual verification
E. Design of packaging	1. Protection from contamination and damage	• Metal cans to prevent contact and shock damage • Statshield™ bags (or similar) for static shielding and moisture protection • Sealed bags with integral desiccants to prevent contamination by moisture • Accelerated age studies to determine ability of sealing methods to reduce storage, transport, and handling impacts
	2. Prediction of performance	• Identification of degradation/deterioration products of critical munition constituents • Sensors to detect and report degradation/deterioration products such as those that are being developed and deployed for the perishable food industry • Improvements in packaging to control materials (i.e., moisture) that lead to degradation/deterioration
F. Manufacture of propellant	1. Production demand fluctuations	• Maximum use of common processes for various munitions to minimize variability • Maintenance of Takt Time for production level loading to minimize the variability inherent in starting and stopping industrial processes
	2. Production discontinuities	• Minimize production discontinuities such as shift changes, breaks, and station rotations, and the variability's therein, by incorporating administrative controls such as staggering breaks • Planning discontinuities to conform to demand and process operations

Table 10
(continued)

Area IV: Maximize reliability (continued)		
Target	Opportunity	Example alternative
F. Manufacture of propellant (continued)	3. Product movement	• Minimization of station-to-station movement by increasing the number of operations at each station, where appropriate • One-piece flow instead of batch processing, with the goal of taking the munition or sub-assembly from one stable condition to the next stable condition in a continuous series of steps without interruption
	4. Variability analysis	• Primary variable control to minimize process variance (for example, gravimetrically controlling charge weight instead of adding a known volume and assuming a density) • Highly repeatable operations; i.e. replace imprecise modes of assembly such as glue joints with push and twist/lock joints • Dimension from a common datum where practical
	5. Processing of raw materials	• Vacuum drying to minimize volatiles in raw materials
	6. Raw material quality	• Independent testing to verify certification data • Actual data measurements for acceptance instead of "go/no-go" or "pass/fail" • Planning and control for lot run-out and change-over of specific constituents during the propellant preparation process • In-process testing and validation • Proper grading and specification of raw materials
	7. Production methods	• Twin-screw extrusion to reduce variability • Drying, combined with improvements in in-process handling procedures, to minimize moisture uptake
	8. Personnel turnover	• Standard Operating Procedures (SOPs)
G. Manufacture of fuze	1. Production demand fluctuations	• Maximum use of common processes for various munitions to minimize variability • Maintenance of Takt Time for production level loading to minimize the variability inherent in starting and stopping industrial processes
	2. Production discontinuities	• Minimization of production discontinuities such as shift changes, breaks, and station rotations by incorporating administrative controls such as staggering breaks • Planning discontinuities to conform to demand and process operations
	3. Product movement	• Minimization of station-to-station movement by increasing operations at each station • One-piece flow instead of batch processing, with the goal of taking the munition or sub-assembly from one stable condition to the next stable condition in a continuous series of steps without interruption
	4. Variability analysis	• Primary variable control to minimize process variance (for example, gravimetrically controlling charge weight instead of addition a known volume and assuming a density) • Highly repeatable operations; i.e., replace imprecise modes of assembly such as glue joints with push and twist/lock joints • Dimension from a common datum where practical
	5. Protection from contamination and damage	• Minimization of component handling to avoid contamination of critical interfaces • Removal of residual packaging material to avoid contamination of interfaces
	6. Static control	• Employing static control to avoid desensitizing the energetic interface and/or causing damage to the electronic fuze components
	7. Raw material quality	• Acquisition of integrated sub-assembly from one manufacturer to reduce variability • Procurement of parts with similar functions/purposes from the same manufacturer to ensure consistency and leverage the inherent benefits of continuous improvements in the manufacturing processes

Table 10
(continued)

Area IV: Maximize reliability (continued)		
Target	Opportunity	Example alternative
G. Manufacture of fuze (continued)	8. Glues and adhesives	• Prevention of glue infiltration into blind passageways between energetic components • Prevention of glue smear on surfaces critical to energetic transfer coupling because adhesives and similar materials can prevent energetic transfer across interfaces
	9. Validation of fuze	• Identification of potential reliability problems through an integrated analysis of storage and surveillance data, training data, field data, and failure data • Evaluation of use of automotive safety systems acceptance model that targets 100% reliability and 100% acceptance – in contrast to Acceptance Quality Level (AQL)-based acceptance, which almost insure that failures will occur in the field
	10. Personnel turnover	• SOPs
H. Manufacture of main charge	1. Production demand fluctuations	• Maximum use of common processes for various munitions to minimize variability • Maintenance of Takt Time for production level loading to minimize the variability inherent in starting and stopping industrial processes
	2. Production discontinuities	• Minimize production discontinuities such as shift changes, breaks, and station rotations, and the variability's therein, by incorporating administrative controls such as staggering breaks • Planning discontinuities to conform to demand and process operations
	3. Product movement	• Minimization of station-to-station movement by increasing the number of operations at each station, where appropriate • One-piece flow instead of batch processing, with the goal of taking the munition or sub-assembly from one stable condition to the next stable condition in a continuous series of steps without interruption
	4. Variability analysis	• Primary variable control to minimize process variance (for example, gravimetrically controlling charge weight instead of adding a known volume and assuming a density) • Highly repeatable operations; i.e., replace imprecise modes of assembly such as glue joints with push and twist/lock joints • Dimension from a common datum where practical
	5. Processing of raw materials	• Use of improved powder drying methods (e.g., vacuum drying) to drive off volatiles and moisture
	6. Raw material quality	• Sampling, testing, and re-baselining of materials when a lot is changed • Control of particle size distributions in raw materials to ensure consistency and reduce variability • Secondary processing (e.g., screening) to remove variability in raw materials
	7. Production methods	• Enhanced solvent removal to maintain included-solvent levels below specified thresholds, combined with specification and maintenance of densities below critical thresholds to prevent exudation of solvent and re-crystallization/deadening of explosive change • Use of processing methods such as incremental loading and flow and compaction conditioners to control density and avoid density gradients that impact sensitivity and output • Use of plasticized main charge energetics (e.g., LX-14) with uniform density to better control sensitivity and output
	8. Personnel turnover	• SOPs

Table 10
(continued)

Area IV: Maximize reliability (continued)		
Target	Opportunity	Example alternative
I. Manufacture of hardware/metal parts	1. Production demand fluctuations	• Maximum use of common processes for various munitions to minimize variability • Maintenance of Takt Time for production level loading to minimize the variability inherent in starting and stopping industrial processes
	2. Production discontinuities	• Minimize production discontinuities such as shift changes, breaks, and station rotations, and the variability therein, by incorporating administrative control such as staggering breaks • Planning discontinuities to conform to demand and process operations
	3. Product movement	• Minimization of station-to-station movement by increasing the number of operations at each station, where appropriate • One-piece flow instead of batch processing, with the goal of taking the munition or sub-assembly from one stable condition to the next stable condition in a continuous series of steps without interruption
	4. Variability analysis	• Primary variable control to minimize process variance (for example, gravimetrically controlling charge weight instead of adding a known volume and assuming a density) • Highly repeatable operations; i.e., replace imprecise modes of assembly such as glue joint with push and twist/lock joints • Dimension from a common datum where practical
	5. Raw material quality	• Sampling, testing, and re-baselining of materials when a lot is changed • Control of particle size distributions in raw materials to ensure consistency and reduce variability • Secondary processing (e.g., screening) to remove variability's in raw materials
	6. Compatibility with energetic	• Selection of materials of construction based on their compatibility with energetic • Use of cleaners and corrosion prevention materials that are (including their residuals) compatible with energetic • Avoidance of use of plasticizers and other elastomeric/polymeric materials that outgas under certain operational and storage conditions related to temperature, humidity, and altitude – such gases can deactivate explosive charges
	7. Protection from contamination and damage	• Avoidance of contamination caused by handling, cleaning residues, and airborne contaminants such as compressed air with entrained oil – all of which can desensitize explosives • Avoidance of contamination caused by residual dunnage such as foam pellets
	8. Personnel turnover	• SOPs
J. LAP facilities	1. Housekeeping	• Employment of Sort, Set in order, Shine, Standardize, Sustain (5S) strategies to improve organization, cleanliness, and standardization of work procedures
	2. Environmental controls	• Effective HVAC filtering for removal of dust and other particular contamination to ensure clean working environment • Purification of air at individual workstations through the use of laminar flow benches • Removal of moisture in both vapor and free droplet form to avoid contamination of product
K. LAP operations	1. Loading processes	• Use of viboratory loading equipment to avoid bridging, classification of particle sizes, and volume/density variations
	2. Optimization of process steps	• Grouping of processes to reduce product handling thereby reducing the chance of variability, reducing contamination, and eliminating potential unreliability

Table 10
(continued)

Area IV: Maximize reliability (continued)		
Target	Opportunity	Example alternative
K. LAP operations (continued)	3. Automation	• Identification of process steps where output is most subject to human variability • Use of automated processes to control/replace manual process steps that lead to variability
	4. Process flow	• Optimization and adherence to established process flow to ensure product quality (such as the order of component blending that can have a dramatic impact on the properties of the final mixture)
	5. Quality assurance	• Identification and rectification of factors that most contribute to the inability of a product to be 100% reliable • Digital imaging for trending and variability control
L. Storage	1. Age	• Establishment and enforcement of standard inventory practices for stock rotation (i.e., first-in, first-out) and age life management
	2. Storage conditions	• Environmental controls to ensure consistent and appropriate temperature and humidity • Grouping of stored materials based on compatibility and sensitivity to contamination • Evaluation of storage procedures to ensure that storage is used in ways consistent with its purpose and design.
Area V: Minimize impacts on range		
A. Prevent exposure	1. Isolation of energetic from environment	• Polymeric coatings to encapsulate the energetic and prevent its exposure to the environment • Strengthening of munition shell (using for example, 4100 series steels) to avoid shell fracturing and exposure of energetic to the environment in the event of a dud that would break up upon impact
	2. Location of incompletely detonated munitions for removal	• Global Positioning Satellite (GPS) systems incorporated into the fuze or main charge to facilitate the location of duds • Magnets incorporated into the munitions for the location of incompletely detonated munitions or duds • RF signaling to locate incompletely detonated munitions and duds
	3. Prevention of sympathetic detonations	• Reduction in shock sensitivity through the use of laminated structures containing low-density materials (e.g., linoleum) to slow down and disrupt shock waves • Modified energetics that are less shock sensitive (such as PBX 9404 used in strategic bombs) that minimize the chances of sympathetic detonation

As part of the GAT methodology, a tool was developed to ensure that a systematic and consistent approach is followed each time the methodology is applied to a different munition item. This tool, presented in appendix A, is a questionnaire that ensures opportunities have not been overlooked and facilitates the identification of specific alternatives. Table1 can be used as a road map for the organization of the questionnaire. Within each area of opportunity, the questionnaire describes specific opportunities for each target listed in table 1 and directs the user, through a series of questions, to define alternatives for each opportunity. Although this is a fairly comprehensive approach, there may be some topics specific to a munition item that has not been listed. Likewise, some topics listed may not be applicable to all munition items. The questionnaire is intended to be generic, covering the five main categories of opportunities discussed previously as well as related opportunities within each of those areas.

Apply Threshold Criteria

Once a list of specific alternatives to reduce range contamination has been developed, Threshold Criteria will be applied to refine the list of alternatives. For the purposes of this project, Threshold Criteria are defined as those criteria that must be met in order for a potential alternative to be considered further. Alternatives that pass the Threshold Criteria will move forward in the process for further assessment. Alternatives that do not pass the Threshold Criteria will be eliminated from further consideration. A record of the eliminated alternatives will be kept along with the rationale for elimination. Threshold Criteria to be used in this analysis include:

- **Mission Readiness** – The proposed alternative must not jeopardize military preparedness by failing to provide soldiers the training needed for combat. It is understood that soldiers must train as they fight to be properly prepared for combat. It is further acknowledged that there are a number of factors that enter into a full evaluation of the impact a given alternative has on mission readiness. For example, the cost of a potential alternative may impact mission readiness if the quality and amount of training is based on the availability of a given, set level of funds. An increase in the unit cost for ammunition will decrease the number of items to be purchased if the budget remains constant. Less ammunition will clearly impact mission readiness. However, for the purposes of this study, only the ability of an alternative to provide for adequate training, independent of cost, is considered as the critical threshold requirement. As described on the next page, cost is considered as a discriminator among those alternatives that are shown to pass the Threshold Criteria.

- **Safety** – The proposed alternative must be as safe as or safer than the baseline or current practice.

- **Range Sustainability** – The proposed alternative must have a net positive impact on range sustainability. In other words, while the proposed alternative would obviously minimize UXO and munitions constituents, it should not have a negative impact on other encroachment issues (e.g., noise, air space, threatened and endangered species, etc.), which contribute to range sustainability.

- **Implementation Feasibility** – The proposed alternative must be able to be implemented in the short term; i.e., 10 years or less. This criterion considers the practicality or reasonableness of implementation based on such factors as technical feasibility, cost, and time to implementation. While these factors are considered later as evaluation criteria, they are used qualitatively as Threshold Criteria to identify and eliminate any alternative that is unsuitable in any of these areas at the present time. Furthermore, implementation feasibility considers logistical obstacles and political/ cultural barriers.

Rate/Rank Alternatives

Alternatives that pass the Threshold Criteria will be assessed based on evaluation criteria and associated weighting factors to rate and rank the potential alternatives. Since alternatives evaluated at this stage of the process will have already passed the Threshold Criteria, use of the evaluation criteria allows for the establishment of a relative comparison between a given alternative and baseline as well as a comparison between a given alternative and other alternatives. It should be noted that since detailed information is unlikely to be available for most alternatives identified, this evaluation is intended to be a qualitative, order-of-magnitude comparison in which large differences are identified.

A procedure for performing the rating/ranking analysis is presented in table 11. Values for each evaluation criterion range from -3 to +3, with +3 being the most favorable score and a value of zero implying baseline equivalency. Numerical weighting factors are assigned to each of the criterion to indicate priority or importance as described below. The overall rank of each alternative is calculated by multiplying the weighting factor for each criterion by the rating for each alternative. The evaluation criteria to be used in this analysis include:

- **Effectiveness** – This criterion addresses how well a proposed alternative achieves the goal of minimizing or preventing energetics contamination from the use of munitions on testing and training ranges. Since all alternatives will be selected based on their ability to minimize or prevent energetics contamination, each of the alternatives will be assigned a rating of greater than "0," which indicates that it is better than the current baseline situation in this respect. Effectiveness is assigned a weighting factor of +3 because, if the alternative is not effective in minimizing the impacts of munitions constituents and contributing to range sustainability, there is little incentive for implementation.

- **Cost** – This criterion addresses the overall cost to implement a proposed alternative. While it is believed that a true life cycle cost of the baseline situation (including the cost of remediation and range closure if the baseline situation were to continue) would outweigh the total cost of implementing the proposed alternative, it is understood that performing complete life cycle cost analyses for both the baseline situation and the implementation of the proposed alternative are significant undertakings and are not included in the scope of this study. Therefore, this evaluation is intended only to be a qualitative, order-of-magnitude comparison in which large differences between the potential alternatives are identified and noted. Each of the alternatives was assigned a rating between –3 and +3. Although an important criterion, based on budget constraints and limited available funds, cost is considered slightly less critical than effectiveness (as described) and is assigned a weighting factor of +2.

- **Schedule** – This criterion addresses the time required for implementation of the proposed alternative. Since the implementation of any alternative will require time, each of the alternatives will be assigned a rating less than "0." Schedule is assigned a weighting factor of +1, because although it is very desirable that an alternative be implemented in a short time, the schedule is less critical to the success of the alternative.

Table 11
Procedure for evaluating alternatives

[illegible]	Effectiveness			Cost			Schedule			
Alternative	Rating (0→+3)	WF	Rating x WF	Rating (-3→+3)	WF	Rating x WF	Rating (-3→0)	WF	Rating x WF	Total = sum of (rating x WF)
1.	X	3	X	X	2	X	X	1	X	X
2.		3			2			1		
3.		3			2			1		
4.		3			2			1		

WF - Weighting factor

After the alternatives have been rated and ranked based on the evaluation criteria, the final step of this procedure is to reconsider the four criteria originally used as Threshold Criteria (i.e., mission readiness, safety, range sustainability, and implementation time) to compare alternatives to the baseline situation. The value of revisiting these four criteria is that it allows for the establishment of a relative comparison (and subsequent discrimination) between a given alternative and other alternatives. Furthermore, it allows the prioritization of alternatives to be adjusted as necessary based on a qualitative application of these four criteria as a whole.

Select Alternatives

Once consensus is reached regarding the rating of each criterion, the alternatives that have the most positive effect with the least amount of negative impact should be recommended for possible implementation.

GAT DEMONSTRATION

The GAT Strategy is to minimize range contamination by focusing on modifications to the design and manufacture stage of the munition life cycle; e.g., maximizing reliability. The GAT Strategy includes a methodology to ensure that a system engineering approach is consistently used and that all impacts are considered when identifying, prioritizing, and recommending design and/or manufacturing changes to minimize range contamination. The GAT methodology was demonstrated on a specific munition item during a meeting held on 1 and 2 February 2005 at ARDEC, Picatinny, New Jersey. Table 12 lists the contact information for the people that participated in the demonstration. This section describes the results of applying the GAT methodology and summarizes the opinions and input of the demonstration participants.

Table 12
List of demonstration participants and contact information

Name	Organization
Melvin Brown	ARDEC/Rock Island
Pete Czachorowski	ARDEC
Shah Dabiri	ARDEC
Tim Dawag	ARDEC
Bill Dunphy	ARDEC
Kim Hogrelius	ARDEC
Eric Jankowski	ARDEC
Kristin Jasinkiewicz	ARDEC
Ramzy Kased	ARDEC
Colette Lamontagne	FOCIS
James Louis	ARDEC
Len Mecca	FOCIS
Robert Moreira	ARDEC
Tom Mueller	ARDEC
Larry Niebuhr	JMC
Fred Oliver	ARDEC
August Thiesing	ARDEC
Mike Wrazen	ARDEC
Tom Wu	ARDEC

Select Munition Item for Analysis

In order to select a munition item for demonstration of the GAT methodology, a list of medium and large caliber rounds (40 mm to 155 mm) with expected training requirements over the next 7 years (FY05 to FY11) was obtained from Program Executive Officer Ammunition (PEO Ammo) and reviewed. From this list, it was observed that the number of rounds required for training varied from a couple thousand rounds to more than a million rounds annually. Guidelines considered when selecting a munition item for analysis included:

- Only medium and large caliber munition items were considered. No small caliber munitions, missiles, or rockets were included in the evaluation at this time. In addition, the selection process was limited to items containing RDX, HMX, or 2,4,6-trinitrotoluene (TNT)-based explosives and propellants. Items containing depleted uranium, items whose main function is smoke generation, and items whose primary constituents are compounds such as perchlorates or white phosphorus were not considered.

- Items were considered as a system. Sub-systems such as fuzes or primers were not selected as stand-alone candidates. While sub-systems were not considered individually, they will be assessed in the course of applying the strategy to the selected munition item.

- Items identified had "sizable" training requirements for each year in FY05 to FY11. Since several munition items shown are expected to have hundreds of thousands of rounds used in training, munition items with an estimated training use of <5,000 rounds annually were not considered for this initial analysis. Selecting those items with training requirements of more than 5,000 rounds annually eliminated all but approximately 20 items.

- 4.2-in. mortar rounds and 8-in. artillery rounds were eliminated from the list of munitions to evaluate since they are no longer in the Army's inventory. Furthermore, 81-mm mortars were maintained on the list of items to be analyzed because, even though they are no longer in production, they are still available in the Army's inventory in significant quantities.

The Munitions Items Disposition Action System (MIDAS) database was then used to calculate the mass of RDX, TNT, and HMX included in the items expected to be used in training. Based on these calculations, the following items were identified as those items using the greatest quantity of explosives:

- 155-mm howitzer (PROJ 155MM HE M107 SERIES W/SUPPL CHG F/HOW M1 M1A1)

- 105-mm howitzer (CTG 105MM HE M1 W/O FUZE F/HOW M2 & M4 SERIES and M49)

Based on the projected use of these two items, it was estimated that the 155-mm howitzer round would result in the use of >3 million pounds of RDX and >2 million pounds of TNT annually, whereas, the 105-mm howitzer round would result in the use of approximately 690,000 lbs RDX and 400,000 lbs TNT annually (assuming rounds are filled with Comp B). Therefore, the 155-mm howitzer (M107 round) was selected for demonstrating the methodology.

Review Systems Requirements

Systems requirements for the integrated weapon system must be reviewed to ensure that the recommended alternatives do not negatively impact system performance. In order to accomplish this step, information presented in a variety of sources (e.g., Technical Manual TM43-0001-28, MIDAS) was reviewed and is included in appendix B.

The M107 was first produced in 1941. It is a hollow steel shell projectile filled with HE. It is the Army's standard HE projectile for all 155-mm howitzers, but is also used for fragmentation, mining, and blast effects. Prior to 2002, the HE fill was 14.6 lbs TNT, but due to supply issues, the HE fill is now 15.4 lbs Composition B (Comp B). This round has either a deep intrusion cavity (4.99 in. max) or a shallow cavity (2.31 in. max). A supplementary charge of 0.36 lbs TNT is available for use when the deep intrusion cavity is used with fuzes other than the M514, M728, or M782. The maximum range is 18.1 km (ref. 18).

There are 10 fuzes that are authorized for use with the M107. Of these, only the M767 and the M782 are currently in production. The authorized fuzes are as follows:

- M557 – This is a point detonating fuze with a delay backup. While it is a very reliable fuze, it is also very sensitive and can be set off by rain so it is no longer being purchased by the United States. However, there are still approximately 2 million in inventory that are being used primarily for training. For service use, this fuze was replaced by the M739.

- M78 series – This is a concrete piercing point detonating fuze that has not been used since before the Vietnam War and is no longer in the inventory. This fuze was replaced by the MK399.

- M739 – This is a point detonating fuze with a delay backup that has been used since the end of the Vietnam War. It is no longer in production, but there are currently approximately 3 million in the inventory.

- MK399 MOD 1 – This is a point detonating fuze with a delay backup that is specially designed for use with hard targets, primarily in combat. It is no longer in production and there are relatively few (about 100,000) in the inventory.

- MTSQ M564 – This is a Mechanical Timed Super Quick (MTSQ) fuze, which is out of production although approximately 120,000 are in the inventory.

- MTSQ M582 series - This is a MTSQ fuze that is no longer in production with approximately 600,000 in the inventory. This fuze has a deep intrusion that is not standard and requires a supplemental charge. Therefore, these fuzes may be demilitarized in preference to being used in training.

- M728 – This is a proximity fuze no longer in production with only about 750,000 in the inventory. This fuze has a deep intrusion that is not standard and requires a supplemental charge. These fuzes were recently transferred to the demilitarization account and are not used in training.

- M732 series - This is a proximity fuze no longer in production with about 300,000 in the inventory. It was determined that this fuze only lasts about 10 years in storage and must be stored with the correct orientation in order to prevent the battery from leaking.

- M767 – This is an electronic-timed fuze with a PBXN-5 or Comp A5 booster that is known to have good reliability. It has been in production since the 1980s and there are currently about 400,000 in the inventory.

- M782 – This is a MOFA, which can be used in four modes (i.e., point detonating, proximity, timed, and delay) with HE rounds. It has a PBXN-5 booster. This fuze is in the material release process and is being fielded to a limited extent. To date, there have been over 250,000 MOFA fuzes produced. The MOFA fuzes are not used in training at this point, but an inert MOFA trainer fuze exists for use in classroom training.

Four types of propellant are authorized for use with the M107: M3, M4, M119, and Modular Artillery Charge System (MACS) M231 and M232 propellant. However, the MACS propellant is the only type that is still in production. M231 is a PAP7993 propellant and M232 is an M30 triple-base propellant.

Identify Potential Alternatives

As shown previously in table 1, opportunities in the Design/Manufacturing Phase of the munition life cycle were examined in order to identify alternatives for minimizing energetics contamination on military ranges. The questionnaire included in appendix A was used to guide the demonstration participants in identifying alternatives that are appropriate for the M107 in each of the areas of opportunity. Table 13 presents the complete list of Design/Manufacturing alternatives identified.

Table 13
Potential alternatives identified

Alternative	Brief description
Opportunity 1. Eliminate energetics	
1. Use electromagnetic technology	Eliminating propellant by using electromagnetic technology to propel the projectile will minimize energetic residue at the firing point
2. Use laser initiation with liquid propellant	Eliminating the primer by using laser initiation with liquid propellant will minimize the energetic material used and reduce the potential for contamination on the range. Using liquid propellant may also improve the combustion efficiency and therefore reduce the residue of propellant at the firing point
3. Use an electronic S&A device; i.e., exploding foil initiator)	Eliminating one or more of the explosive train elements by using an exploding foil initiator will minimize the energetic material used and reduce the potential for contamination on the range
4. Use an electronic S&A; i.e., high voltage driven semi-conductor bridge elements	Eliminating one or more of the explosive train elements by using high voltage driven semi-conductor bridge elements will minimize the energetic material used and reduce the potential for contamination on the range
5. Use direct laser initiation	Eliminating the explosive train by using direct laser initiation of the main charge will minimize the energetic material used and reduce the potential for contamination on the range
6. Increase the use of the M804A1 training round	Maximizing the use of existing training rounds without explosive main charges may reduce the number of live rounds used in training and thus minimize the potential for release of energetic material on ranges
7. Modify the M107 round with inert filler and a smoke charge in an aluminum liner	Reducing the cost of training rounds without explosive main charges by modifying the M107 and putting the smoke charge in a less expensive aluminum liner instead of the steel can may reduce the number of live rounds used in training and thus minimize the potential for release of energetic material on ranges
8. Modify the M804A1 training round to increase the signature	Increasing the realism of the M804A1 training round may reduce the number of live rounds used in training and thus minimize the potential for release of energetic material on ranges.
9. Eliminate the main charge by using the existing technical data package to produce the M804A1 with cast iron	Reducing the cost of training rounds without explosive main charges by using less expensive material (i.e., cast iron versus forged steel) may reduce the number of live rounds used in training and thus minimize the potential for release of energetic material on ranges.
Opportunity 2. Substitute energetics	
10. Substitute RDX booster with TBXN-5	Removing the RDX booster will minimize the amount of RDX potentially released on the ranges
11. Substitute RDX booster with pressed TNT	Removing the RDX booster will minimize the amount of RDX potentially released on the ranges
12. Substitute RDX booster with another green IM explosive	Removing the RDX booster will minimize the amount of RDX potentially released on the ranges
13. Substitute the main charge with an ammonium nitrate filler in a training round	Designing a new or modified training round that uses more environmentally-acceptable energetics in the main charge may minimize the potential release of energetic material
14. Substitute the main charge with TNT in a dual use round	Selecting and using existing rounds that are filled with more environmentally-acceptable energetics may minimize the potential release of energetic material
15. Substitute the main charge with a new "green" explosive in a dual use round	Designing a new round filled with more environmentally-acceptable energetics may minimize the potential release of energetic material.

Table 13
(continued)

Alternative	Brief description
Opportunity 3. Reduce energetics	
16. Optimize the geometry of the fuze booster	Varying the geometry of the fuze booster may allow a reduction in the quantity of booster material required to ignite the main charge and minimize the potential for release of energetic material on ranges
17. Optimize the booster initiation geometry; e.g., using peripheral initiation	Implementing an optimal initiation geometry (e.g., using peripheral initiation) may reduce the quantity of booster and main charge required and minimize the potential for release of energetic material on ranges
18. Use multipoint initiation	Using multipoint initiation may reduce the quantity of booster and main charge required by creating a higher output-inducing wave front of colliding shock waves, thereby minimizing the potential for release of energetic material on ranges
19. Use two smaller boosters	Using two smaller boosters to yield more output per unit energetic may reduce the quantity of the main charge required and minimize the potential for release of energetic material on ranges
20. Use an HMX-based higher output energetic in the main charge	Using higher output energetics may reduce the quantity required to achieve the desired performance of the main charge and, in turn, may reduce the magnitude of possible future release of energetic material
21. Reduce the quantity of main charge required by using PAX-196	Using higher output energetics may reduce the quantity required to achieve the desired performance of the main charge and, in turn, may reduce the magnitude of possible future release of energetic material
Opportunity 4. Maximize reliability	
22. Include a self-destruct feature in the M767 and M782 MOFA fuzes	Incorporating a self-destruct feature would minimize the occurrence of UXO on a range
Opportunity 5. Minimize environmental impact	
23. Use liquid propellant instead of solid propellant	The impact of munition use could be minimized by using liquid propellant with a higher combustion efficiency thereby reducing the propellant residue at the firing point
24. Incorporate a polymeric coating for the main charge	Designing a munition with a polymeric coating around the main charge may provide an additional barrier between the explosive and the environment if the metal shell of a UXO corrodes
25. Incorporate a polymeric lining for the munition shell	Designing a polymeric lining along the inside wall of the munition shell may provide an additional barrier between the explosive and the environment if the metal shell of a UXO corrodes
26. Increase the thickness of the munition shell	Increasing the thickness of the munition shell may increase the time to perforation of a UXO shell thus prolonging the time required to expose the explosive to the environment
27. Use more corrosion resistant material for munition shell	Increasing the ability of the munition shell to resist corrosion would increase the time to perforation by corrosion of a UXO
28. Use improved corrosion inhibitors on the munition shell	Increasing the degree of corrosion inhibition of the munition shell would increase the time to perforation by corrosion of a UXO
29. Incorporate magnets into munitions	Incorporating a small magnet into rounds used in training may improve the ability to locate and remove UXO from the range
30. Use RF signals to locate duds	Incorporating RF tag or transmitter into a training round may improve the ability to locate and remove UXO from range
31. Reduce the shock sensitivity of the round	Designing a round with reduced shock sensitivity may decrease the likelihood that a UXO will experience a low order detonation when another round detonates nearby. Avoiding low order detonations may reduce the potential for future range contamination
32. Use modified energetics that are less shock sensitive	Using less shock sensitive modified "green" energetics may decrease the likelihood that a UXO will experience a low order detonation when another round detonates nearby. Avoiding low order detonations may reduce the potential for future range contamination
33. Add a taggant to the main charge	Adding a material to the energetic that would allow for energetic contamination to be more easily detected on the range may facilitate the identification of specific areas that require remediation

Eliminate Energetics

Nine potential alternatives were identified to eliminate energetics from the propellant, fuze, or main charge of the M107. Of these, four alternatives (alternatives 6 through 9) involve making changes that will encourage the increased use of training practice rounds without an energetic main charge.

Currently, the M804/M804A1 training practice round can be used in lieu of the M107 (see appendix C for information on the M804/M804A1 projectile). The M804/M804A1 projectile is the same as the M107 except that the shell has thicker walls to compensate for the lack of explosive fill. In addition, the M804 has a 190 g smoke charge in an aluminum tube with four holes in the shell and the M804A1 has a 450 g smoke charge with a 20 g Comp A5 pellet in a steel cup. The smoke charge provides a visual signature for the Forward Observer to detect where the projectile landed. This training round was designed to have a reduced noise signature compared to the M107 round. (Note: the M804 is not currently in production, so the remaining discussion will refer only to the M804A1.)

While this training round meets the requirements for training (visible from 4000 m), there are those who believe that due to the lack of a realistic visual and noise signature, the round does not allow the soldiers to train as they fight and therefore should not be used for training. Furthermore, the M804A1 is more expensive to manufacture than the M107. This is due primarily to the low quantities of M804A1 projectiles purchased annually compared to the M107. Typical orders are about 20,000 M804A1 projectiles over 5 years versus 200,000 M107 projectiles per year. In addition, there is no direct cost to the Army for stockpiled Comp B, so any cost associated with filler or alternative explosive material in the training round would make the training round comparatively more expensive. Cost differences may also be attributed to the thicker steel walls of the M804A1 and to the cost of the thin-walled, heat-treated, hollow steel cup holding the smoke charge in the M804A1.

Consequently, alternatives were identified to increase the use of the M804A1 by either decreasing the cost or improving the realism of the visual and noise signature. Alternative 6 implies that if an increase in the use of M804A1 projectiles for training were mandated by the Army, the cost per item would decline due to the greater demand and production of these items since the M804A1 and M107 are manufactured by the same contractor on the same production line. While alternative 6 involves changes to the testing/training Phase of the munition life cycle, it was not eliminated from the list of potential alternatives for the purposes of this study because it also involves changes to the manufacturing process due to the increase in production. Alternative 7 attempts to lower the cost of the item by using the thinner walled M107 shell while placing the smoke charge in a less expensive aluminum liner with inert filler. Alternative 8 recommends modifying the current M804A1 round to include slightly more explosive to improve the visual and noise signature. Obviously, the amount and type of explosive selected would have to minimize the potential for range contamination relative to the M107. Alternative 9 attempts to decrease the unit cost of the M804A1 by producing it of cast iron. A technical data package for production with cast iron already exists, but no vendors have bid on that item to date. (Note: This alternative is based on the assumption that manufacturing the projectile from cast iron is less expensive than from forged steel. If cast iron proves to be more expensive, this alternative should be eliminated.)

Substitute Energetics

The environmental impact of an energetic material can be based on toxicity, exposure, or other factors, so a consensus should be reached on the impacts of each explosive prior to recommending a substitution. For the purposes of the GAT Demonstration with the M107, it was assumed that RDX is the least desirable explosive since it is very mobile in the environment and may reach the groundwater more quickly than TNT or HMX, which tend to biodegrade or adsorb to the soil. With this in mind, six potential alternatives were identified to substitute energetics from the propellant, fuze, or main charge of the M107. Three of the alternatives involved replacing the RDX fuze booster with PBXN-5, pressed TNT, or another more environmentally-friendly explosive under development. The remaining three alternatives involved replacing the Comp B (comprised of approximately 60% RDX, 39% TNT, and 1% wax) main charge with ammonium nitrate, TNT, or another more environmentally-friendly explosives under development.

Reduce Energetics

Six potential alternatives were identified to reduce energetics from the propellant, fuze, or main charge of the M107 to achieve the same performance of the projectile while still minimizing potential range contamination. Two of these alternatives addressed optimization of the fuze booster, two alternatives addressed optimization of initiation of the main charge, and two alternatives suggested using higher output explosives in the main charge.

Maximize Reliability

Based on discussions with demonstration participants, the reliability of the M107 explosive train is quite high, approaching 100% if the operation of the fuze is not considered. This high reliability can be attributed to the fact that it has been a critical munition item in high demand since at least 1999. Continuous full-scale production has allowed for the elimination of many of the inherent manufacturing fluctuations that can lead to low reliability. In addition, a long-term contract was recently awarded to American Ordnance (AO) to produce the M107. A long-term contract allows the time to optimize a production line and also provides the incentive for the contractor to invest in quality improvements. The M107 production line was subjected to a Six Sigma review recently and ARDEC has been working with AO since 2001 to resolve many production issues for the M107. Consequently, many of the opportunities for maximizing reliability presented in the GAT methodology have already been addressed for the M107. Examples of areas being addressed and/or quality improvements implemented include:

- AO prefers not to use TNT from Poland because they believe the particle size is too variable and inconsistent. This issue is currently being investigated.
- AO uses two 10-hr shifts and a 4-hr "stub" shift to minimize production discontinuities.
- It was determined that the day shift (with the senior, more experienced employees) was producing a more consistent product than the night shift until controls were established. Currently, both shifts are equally reliable.
- It was determined that SOPs and visual standards should be documented and clearly posted since union workers often rotate between jobs and there can be a new crew of employees each week.

- A controlled cooling environment is critical to the pouring operation, so humidity and temperature are tracked. It must be 90°F in the packing room to accommodate the pretreated metal parts. If conditions outside the approved range are experienced, the rounds are segregated and x-rayed for defects. If no defects are found, a request for approval to use these items is submitted in writing to the Joint Munitions Command.

- Even when required controlled conditions are maintained, all rounds are x-rayed in order to detect flaws such as cracks, voids, foreign material, annular rings, cavities, or piping in the explosive material.

- Insulation was installed in the tunnels between the work stations to maintain controlled conditions.

- AO is considering the use of a water bath instead of air to more rapidly and more uniformly heat the projectiles.

- Automation was added to the production line by the incorporation of an automatic weighing scale that marks the weight zone (1 to 5 in 0.5 lb increments) on the side of the projectile with a stencil and a punch code.

All demonstration participants agreed that if low order detonations or duds occur, it is usually due to failure of the fuze. (See the Review Systems Requirements section for a description of authorized fuzes). Some examples of fuze failures provided by the demonstration participants include:

- If a round does not hit a clean, hard surface directly, a point detonating fuze may not function.

- If the ogive of the projectile deforms before the fuze functions, it is likely that a dud or low order detonation will occur.

- Failures were encountered with the M732 fuze when it contained only a small 6-gm booster. However, the reliability improved with the incorporation of a 20-gm booster or when the booster was used in conjunction with a supplementary charge of 1/3 lb pressed TNT.

- Failures were encountered with the M582 fuze because lubricant in the safe and Arm (S&A) mechanism dried out, which negatively affected the timing function.

Neither of the two fuzes that are currently, or soon to be, in production (M767 and M782 MOFA) have a redundant channel. With a redundant channel, if one function fails the second function may succeed in creating a high order detonation as is seen in the M557 and M739 fuzes (which have point detonating and delay functions). Therefore, an alternative was identified to include a self-destruct feature (based on a timed function) with the M767 and M782 MOFA fuzes to cause their detonation and minimize the quantity of UXO on the ranges.

Minimize Environmental Impact

Assuming that low order detonations and duds might still occur even if opportunities in the first four categories are implemented, 11 potential alternatives involving design changes were identified to minimize the environmental impacts of low order detonations and duds once on the range. One alternative suggests using liquid propellant to reduce propellant residue at the firing point, five alternatives address ways to prolong exposure of the energetic material to the environment, three alternatives address methods for improving detection of UXO or energetic material on the range, and two alternatives address ways to reduce the occurrence of sympathetic detonations.

It should be noted that the demonstration participants also identified two alternatives that fall into the testing/training and range maintenance Phases of the munition life cycle. While these are not included in the scope of the GAT project, the alternatives were documented for future efforts.

1. Increase the use of virtual training with computer simulations and "dry fire" exercises. Reducing the number of live fire exercises by replacing them with computer simulations and with "dry fire" exercises, in which soldiers perform all of the normal procedures except for pulling the lanyard, may reduce the release of energetic material on the range.

2. Position 2D or 3D seismic sensors underground in the impact area. These devices may facilitate the detection and removal of UXO.

Apply Threshold Criteria

Threshold Criteria were defined to be criteria that each alternative must satisfy or be immediately eliminated. The Threshold Criteria were applied to the list of potential alternatives to eliminate those alternatives that were unacceptable. As described previously in the Apply Threshold Criteria section, the Threshold Criteria used in this analysis includes: mission readiness, safety, range sustainability, and implementation feasibility.

Table 14 presents the list of potential alternatives identified and indicates whether each alternative passed the Threshold Criteria. Overall, six alternatives were eliminated because they did not pass the Threshold Criteria. One alternative was eliminated based on mission readiness and implementation feasibility, three alternatives were eliminated based on safety, and two alternatives were eliminated based on implementation feasibility, The alternatives that passed the Threshold Criteria moved forward in the process for further assessment. The alternatives that did not pass the Threshold Criteria were eliminated from further consideration. These eliminated alternatives and the rationale for their elimination are described next.

Alternative 1: Use Electromagnetic Technology

This alternative was eliminated from further consideration because it did not pass the implementation feasibility criterion. While this technology is being developed commercially to launch planes from aircraft carriers (as an alternative to the current use of compressed steam), it is not under intensive development by the Army to replace munition propellant. Therefore, it is believed that the implementation time would be greater than 10 yrs.

Alternative 2: Use Laser Initiation With Liquid Propellant

This alternative was eliminated from further consideration because it did not pass the safety criterion. Unexplained pressure spikes were experienced with liquid propellant. This technology was being developed for the Crusader program, but since that program was terminated, this technology is no longer under intensive development by the Army.

Alternative 11: Substitute RDX Booster with Pressed TNT

This alternative was eliminated from further consideration because it did not pass the safety criterion. TNT is not considered an appropriate explosive for use in Insensitive Munitions (IM).

Alternative 23: Use Liquid Propellant Instead of Solid Propellant

This alternative was eliminated from further consideration because it did not pass the safety criterion. Unexplained pressure spikes were experienced with liquid propellant and it is no longer under intensive development by the Army.

Alternative 24: Incorporate a Polymeric Coating for the Main Charge

This alternative was eliminated from further consideration because it did not pass the implementation feasibility criterion. The main charge for the M107 projectile is melted, poured into the munition body from the fuze end, and cured. In order to apply a polymeric coating, it would be necessary to create a mold of the main charge, coat it, and then insert it into the round from the base. The fragmentation pattern could be altered if the shell consisted of multiple pieces. The technology to load the main charge from the base does exist. However, the cost, time, and logistics required to design, manufacture, and integrate new rounds into the stockpile make it impractical at this time.

Alternative 26: Increase the Thickness of the Munition Shell

This alternative was eliminated from further consideration because it did not pass the mission readiness criterion or the implementation feasibility criterion. Increasing the thickness of the munition shell in order to increase the time to perforation due to corrosion would change the weight, ballistics, and possibly the performance of the round. In order to maintain the same weight and ballistics, the mass of explosive might have to be reduced which, in combination with increased wall thickness, would affect the desired output such as the fragmentation pattern. Furthermore, the technology, cost, time, and logistics required to design, manufacture, and integrate new rounds into the stockpile make it impractical at this time.

Table 14
Potential alternatives and Threshold Criteria

Alternative	Pass/fail	Threshold Criteria: Mission readiness	Safety	Range sustainability	Implementation feasibility
Opportunity 1. Eliminate energetics					
1. Use electromagnetic technology	F	√	√	√	X
2. Use laser initiation with liquid propellant	F	√	X	√	√
3. Use an electronic S&A; i.e., exploding foil initiator	P	√	√	√	√
4. Use an electronic S&A; i.e., high voltage driven semi-conductor bridge elements	P	√	√	√	√
5. Use direct laser initiation	P	√	√	√	√
6. Increase the use of the M804A1 training round	P	√	√	√	√
7. Modify the M107 round with inert filler and a smoke charge in an aluminum liner	P	√	√	√	√
8. Modify the M804A1 training round to increase the signature	P	√	√	√	√
9. Eliminate the main charge by using the existing technical data package to produce the M804A1 with cast iron	P	√	√	√	√
Opportunity 2. Substitute energetics					
10. Substitute RDX booster with PBXN-5	P	√	√	√	√
11. Substitute RDX booster with pressed TNT	F	√	X	√	√
12. Substitute RDX booster with another green IM explosive	P	√	√	√	√
13. Substitute the main charge with an ammonium nitrate filler in a training round	P	√	√	√	√
14. Substitute the main charge with TNT in a dual use round	P	√	√	√	√
15. Substitute the main charge with a new "green" explosive in a dual use round	P	√	√	√	√
Opportunity 3. Reduce energetics					
16. Optimize the geometry of the fuze booster	P	√	√	√	√
17. Optimize the booster initiation geometry; e.g., using peripheral initiation	P	√	√	√	√
18. Use multipoint initiation	P	√	√	√	√
19. Use two smaller boosters	P	√	√	√	√
20. Use an HMX-based higher output energetic in the main charge	P	√	√	√	√
21. Reduce the quantity of main charge required by using PAX-196	P	√	√	√	√
Opportunity 4. Maximize reliability					
22. Include a self-destruct feature in the M767 and M782 MOFA fuzes	P	√	√	√	√
Opportunity 5. Minimize environmental impact					
23. Use liquid propellant instead of solid propellant	F	√	X	√	√
24. Incorporate a polymeric coating for the main charge	F	√	√	√	X
25. Incorporate a polymeric lining for the munition shell	P	√	√	√	√
26. Increase the thickness of the munition shell	F	X	√	√	X
27. Use more corrosion resistant material for munition shell	P	√	√	√	√
28. Use improved corrosion inhibitors on the munition shell	P	√	√	√	√
29. Incorporate magnets into munitions	P	√	√	√	√
30. Use RF signals to locate duds	P	√	√	√	√
31. Reduce the shock sensitivity of the round	P	√	√	√	√
32. Use modified energetics that are less shock sensitive	P	√	√	√	√
33. Add a taggant to the main charge	P	√	√	√	√

√ - Meets criterion
X – Fails criterion

Rate/Rank Alternatives

As described previously (Rate/Rank Alternatives section), alternatives that passed the Threshold Criteria were assessed based on a second set of more detailed evaluation criteria. The values for each evaluation criterion ranged from -3 to +3, with +3 representing the most favorable score, -3 representing the least favorable score, and a value of 0 implying baseline equivalency. The evaluation criteria used in this analysis included: effectiveness, cost, and schedule. Numerical weighting factors were assigned to each of the criterion to indicate priority or importance.

Table 15 lists the alternatives that passed the Threshold Criteria, presents the rating applied for each evaluation criterion for each alternative, and presents the overall rank for each alternative. The overall rank of each alternative was calculated by multiplying the weighting factor for each criterion by the rating for each alternative.

Table 15
Evaluation of alternatives

Evaluation criteria →	Effectiveness			Cost			[illegible]			
Alternative ↓	Rating (0→+3)	WF	Rating x WF	Rating (-3→+3)	WF	Rating x WF	Rating (-3→0)	WF	Rating x WF	Total = sum of (rating x WF)
Opportunity 1. Eliminate energetics										
3. Use an electronic S&A; i.e., exploding foil initiator	1	3	**3**	-3	2	**-6**	-2	1	**-2**	**-5**
4. Use an electronic S&A; i.e., high voltage driven semi-conductor bridge elements	1	3	**3**	-3	2	**-6**	-2	1	**-2**	**-5**
5. Use direct laser initiation	1	3	**3**	-1	2	**-2**	-3	1	**-3**	**-2**
6. Increase the use of the M804A1 training round	3	3	**9**	-1	2	**-2**	0	1	**0**	**7**
7. Modify the M107 round with inert filler and a smoke charge in an aluminum liner	3	3	**9**	-2	2	**-4**	-1	1	**-1**	**4**
8. Modify the M804A1 training round to increase the signature	3	3	**9**	-1	2	**-2**	-1	1	**-1**	**6**
9. Eliminate the main charge by using the existing technical data package to produce the M804A1 with cast iron	3	3	**9**	0	2	**0**	0	1	**0**	**9**
Opportunity 2. Substitute energetics										
10. Substitute RDX booster with PBXN-5	1	3	**3**	-1	2	**-2**	-3	1	**-3**	**-2**
12. Substitute RDX booster with another green IM explosive	1	3	**3**	-2	2	**-4**	-3	1	**-3**	**-4**
13. Substitute the main charge with an ammonium nitrate filler in a training round	2	3	**6**	-2	2	**-4**	-2	1	**-2**	**0**
14. Substitute the main charge with TNT in a dual use round	1	3	**3**	-1	2	**-2**	-1	1	**-1**	**0**
15. Substitute the main charge with a new "green" explosive in a dual use round	1	3	**3**	-3	22	**-6**	-3	1	**-3**	**-6**
Opportunity 3. Reduce energetics										
16. Optimize the geometry of the fuze booster	1	3	**3**	-1	2	**-2**	-3	1	**-3**	**-2**
17. Optimize the booster initiation geometry; e.g., using peripheral initiation	1	3	**3**	-1	2	**-2**	-3	1	**-3**	**-2**
18. Use multipoint initiation	2	3	**6**	-3	2	**-6**	-3	1	**-3**	**-3**
19. Use two smaller boosters	2	3	**6**	-3	2	**-6**	-3	1	**-3**	**-3**

Table 15
(continued)

Evaluation criteria→	Effectiveness			Cost			Schedule			
Alternative ↓	Rating (0→+3)	WF	Rating X WF	Rating (-3→+3)	WF	Rating X WF	Rating (-3→0)	WF	Rating X WF	Total = sum of (rating x WF)
Opportunity 3. Reduce Energetics (continued)										
20. Use an HMX-based higher output energetic in the main charge	1	3	**3**	-3	2	**-6**	-3	1	**-3**	**-6**
21. Reduce the quantity of main charge required by using PAX-196	0	3	**0**	-3	2	**-6**	-3	1	**-3**	**-9**
Opportunity 4. Maximize reliability										
22. Include a self-destruct feature in the M767 and M782 MOFA fuzes	2	3	**6**	-2	2	**-4**	-3	1	**-3**	**-1**
Opportunity 5. Minimize environmental impact										
25. Incorporate a polymeric lining for the munition shell	1	3	**3**	-2	2	**-4**	-2	1	**-2**	**-3**
27. Use more corrosion resistant material for munition shell	1	3	**3**	-3	2	**-6**	-3	1	**-3**	**-6**
28. Use improved corrosion inhibitors on the munition shell	0	3	**0**	-1	2	**-2**	-1	1	**-1**	**-3**
29. Incorporate magnets into munitions	1	3	**3**	-2	2	**-4**	-1	1	**-1**	**-2**
30. Use RF signals to locate duds	1	3	**3**	-2	2	**-4**	-1	1	**-1**	**-2**
31. Reduce the shock sensitivity of the round	0	3	**0**	-3	2	**-6**	-3	1	**-3**	**-9**
32. Use modified energetics that are less shock sensitive	0	3	**0**	-3	2	**-6**	-3	1	**-3**	**-9**
33. Add a taggant to the main charge	0	3	**0**	-2	2	**-4**	-1	1	**-1**	**-5**

WF – Weighting factor

It should be noted that due to time constraints during the Demonstration, discussions regarding the advantages/disadvantages of each alternative as well as the subsequent evaluation were limited. The ratings (for effectiveness, cost, and schedule) agreed upon by the demonstration participants were qualitative, relative ratings and were not based on extensive research. However, this exercise did result in providing a relative comparison of a given alternative to the baseline scenario and to other alternatives. In addition, the ratings given to each alternative by the demonstration participants were based on the assumption that the fuzes currently in the inventory would have to be consumed or demilitarized prior to using a new or modified fuze.

Specific comments noted during the alternative evaluation include:

- Alternatives 3 and 4 involve the use of electronic S&As. The exploding foil initiator and the high voltage driven semi-conductor bridge elements were investigated by ARDEC, but were determined to be cost and space prohibitive.

- Alternative 5 involves the use of a laser to initiate the main charge, thereby eliminating the need for an explosive train. It is believed that implementation of this alternative would require about 10 yrs.

- Alternative 6 suggests increasing the use of the M804A1 training round. The cost of this practice round is higher than that of the M107 HE round. However, if an increase in the use of M804A1 projectiles for training were mandated by the Army, the cost per item would decline due to the greater demand and production of these items since the M804A1 and M107 are manufactured by the same contractor on the same production line. This alternative could also be implemented right away since training rounds are currently available for the M107 HE round and are included in Army acquisition plans for continued production.

- Alternative 7 involves modifying the M107 round with inert filler and a smoke charge in an aluminum liner. The cost for this practice round may be higher than the M107 HE round due to the design requirements and smoke charge, but it may be less expensive than or equal to the existing M804A1 if the steel cup can be replaced by an aluminum liner. These modified M107 rounds would require some design work and time to prepare the production lines.

- Alternative 8 involves modifying the M804A1 training round to increase the signature. Modifying the current M804A1 round to include slightly more explosive material to improve the visual and noise signature would make this round more desirable to soldiers being trained. However, the amount and type of explosive selected would have to be more environmentally-friendly or minimize the potential for range contamination relative to the M107. The cost for this practice round may be higher than the M107 HE round due to the design requirements and smoke charge, but it may be less expensive than or equal to the existing M804A1, if increased acceptance and demand result in increased production. The modified M804A1 rounds would require some design work and time to prepare the production lines.

- Alternative 9 attempts to eliminate the main charge by using the existing technical data package to produce the M804A1 with cast iron. While the cost of the cast iron shell may be less than the steel shell, the addition of a smoke charge may make the overall cost equal to the M107 HE round. In addition, a technical data package for production with cast iron already exists so the alternative could be implemented in a short timeframe. However, it should be noted that in the past, no contractor has bid on the production of M804A1 rounds with cast iron.

- Alternative 13 suggests designing a training round with ammonium nitrate as the main charge. This alternative would have to be reviewed for safety before it could be implemented.

- Alternatives 13, 14, and 15 involve substitution of the Comp B main charge with other explosives. It should be noted that there are cost implications since there is currently no direct cost to the Army for the use of stockpiled Comp B. Therefore, any other explosive is inherently more expensive. The required design effort and performance and safety testing also add to the cost.

- Alternative 16 involves reducing the booster quantity required by optimizing the geometry. This technology is used on larger scale applications. Wave shaping the booster may optimize the propagation so that less explosive material would be required, but it would be a very small reduction and any free volume would present a safety concern due to adiabatic compression. It is believed that implementation of this alternative would require 5 to 10 yrs.

- Alternative 21 suggests using PAX-196 in place of Comp B for the main charge. PAX-196 has a higher energy output than Comp B so that the quantity required can be reduced. However, PAX-196 is still RDX-based (80% RDX and 20% wax) and has a greater percentage of RDX than Comp B (60% RDX, 39% TNT, 1% wax).

- Alternative 22 involves redesigning the M767 and MOFA fuzes to include a self-destruct feature. This alternative is either very costly or very time intensive to implement, since there are so many other fuzes already in the inventory that would either have to be demilitarized or used up prior to using the new fuzes. It may also be difficult to design a self-destruct feature given the space limitation within the fuze.

- Alternatives 25, 27, and 28 suggest methods for preventing the exposure of the explosive to the environment. However, the effectiveness of these alternatives would be very low since they would only be prolonging the ultimate exposure of the explosive to the environment. In addition, using a material that is more corrosion resistant than steel for the projectile body would be very expensive.

- Alternatives 29 and 30 address methods for facilitating the location of UXO so that they can be removed from the range, thereby eliminating a potential source of contamination. However, due to the mass of the M107, UXO tend to be buried many feet below the surface. In this case, the effectiveness of these alternatives would be reduced.

- Alternatives 31 and 32 address methods for minimizing the impact of sympathetic detonations. However, due to the size of M107 projectiles, UXO tend to be buried many feet underground. Therefore, sympathetic detonations are rare and the effectiveness of these alternatives is minimal.

- Alternative 33 suggests adding a taggant to the explosive to facilitate detection on the range. However, there are practical limitations to the vapor phase detection of tagged and untagged explosives. Furthermore, if contained in a sealed UXO, they are not likely to be detected by any currently available technology. Due to the mass of the M107, UXO tend to be buried many feet below the surface. In this case, the effectiveness of this alternative would be minimal even if the UXO were perforated.

Select Alternatives

Once the alternatives were ranked according to the evaluation criteria, weighting factors, and ratings, the overall (i.e., total) ratings were assessed to ensure consistency of each rating to the base criteria of mission readiness, safety, range sustainability, and implementation feasibility. Table 16 lists the alternatives in order of their overall rating, with a high positive number indicating a more favorable alternative. It should be noted that the demonstration participants strongly believed that prior to recommending implementation of any alternatives, it is necessary to consult the user community. However, the top seven of the original 33 potential alternatives were recommended for further consideration. The selected alternatives involve the use of various training rounds and the incorporation of self-destruct fuzes.

Table 16
Summary of alternative evaluation results

Alternative (in order of rating, high to low)	Overall rating*
9. Eliminate the main charge by using the existing technical data package to produce the M804A1 with cast iron	9
6. Increase the use of the M804A1 training round	7
8. Modify the M804A1 training round to increase the signature	6
7. Modify the M107 round with inert filler and a smoke charge in an aluminum liner	4
13. Substitute the main charge with an ammonium nitrate filler in a training round	0
14. Substitute the main charge with TNT in a dual use round	0
22. Include a self-destruct feature with the M767 and MOFA fuzes	-1
5. Use direct laser initiation	-2
10. Substitute RDX booster with PBXN-5	-2
16. Optimize the geometry of the fuze booster	-2
17. Optimize the booster initiation geometry; e.g., using peripheral initiation	-2
29. Incorporate magnets into munitions	-2
30. Use RF signals to locate duds	-2
25. Incorporate a polymeric lining for the munition shell	-3
18. Use multipoint initiation	-3
19. Use two smaller boosters	-3
28. Use improved corrosion inhibitors on the munition shell	-3
12. Substitute RDX booster with another green IM explosive	-4
3. Use an electronic S&A; i.e., exploding foil initiator	-5
4. Use an electronic S&A; i.e., high voltage driven semi-conductor bridge elements	-5
33. Add a taggant to the main charge	-5
15. Substitute the main charge with a new "green" explosive in a dual use round	-6
20. Use an HMX-based higher output energetic in the main charge	-6
27. Use more corrosion resistant material for munition shell	-6
21. Reduce the quantity of main charge required by using PAX-195	-9
31. Reduce the shock sensitivity of the round	-9
32. Use modified energetics that are less shock sensitive	-9

*Overall rating = weighted effectiveness rating + weighted cost rating + weighted schedule rating

Appendix A
Questionnaire for Identifying Opportunities

I. Eliminate the use of energetics

The following questions address opportunities for reducing the potential for energetic contamination at training/testing ranges by replacing the energetic function with alternative technologies and/or materials.

I-A. Opportunity: Eliminate propellant.
1. **Alternative technology.** *Alternative technologies, such as electromagnetics and hydrogen combustion, have the potential to replace propellant energetics.*
Is it feasible to replace propellant with another technology? If yes, list.
Are technology replacements for propellants available? If yes, list and describe as necessary.
Are technology replacements for propellants under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

I-B. Opportunity: Eliminate fuze energetics.
1. **Alternative technology.** *Alternative fuze technologies, such as electronics, have the potential to replace the energetic functions in the fuze train.*
Is it feasible to replace fuze energetics with another technology? If yes, list.
Are technology replacements for fuze energetics available? If yes, list and describe as necessary.
Are technology replacements for fuze energetics under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

I-C. Opportunity: Eliminate main charge energetics.
1. **Non-energetic material.** *Non-energetic materials (e.g., concrete) may be used to replace energetics in training rounds to reduce their environmental impact while providing a realistic training experience through the launch sequence.*
Are non-energetic materials feasible to replace energetics in training rounds? If yes, list.
Are such replacements for the main charge energetics available? If yes, list and describe as necessary.
Are such replacements for main charge energetics under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

II. Substitute more environmentally-acceptable materials for energetics currently used in this munition

The following questions address opportunities for replacing currently-used energetics with alternative formulations that achieve the same, or greater, performance; are as safe or safer; and have less of an environmental impact.

II-A. Opportunity: Use more environmentally-acceptable propellants.
1. **More environmentally-acceptable energetics.** *Replacing currently-used propellants with more environmentally-acceptable formulations can reduce the environmental impact.*
Can more environmentally-acceptable propellant formulations be used in this munition? If no, why not?
Are such propellant formulations available? If yes, list and describe as necessary.
Are such propellant formulations under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

II-B. Opportunity: Use more environmentally-acceptable energetics in the fuze.
1. **More environmentally-acceptable energetics.** *Replacing currently-used fuze energetics with more environmentally-acceptable formulations can reduce the environmental impact.*
Can more environmentally-acceptable energetics be used in this fuze train? If no, why not?
Are such energetics for the fuze available? If so, list and describe as necessary.
Are such energetics for the fuze under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

II-C. Opportunity: Use more environmentally-acceptable energetics in the main charge.
1. **More environmentally-acceptable energetics.** *Replacing currently-used fuze energetics with more environmentally-acceptable formulations can reduce the environmental impact.*
Can more environmentally-acceptable explosives be used in this munition? If no, why not?
Are such explosives available? If yes, list and describe as necessary.
Are such explosives under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

III. Reduce the quantity of energetics required in this munition

The following questions address opportunities for reducing the total quantity of energetics used in the munition thereby reducing the magnitude of potential energetic contamination at training/test ranges.

III-A. Opportunity: Reduce propellant quantity
1. Optimization of quantity required. *Computer models and simulations can be used to determine the optimal amount of propellant required to achieve desired performance.*
Does a valid model to determine the optimal amount of propellant exist?
Has the model been run to determine the minimum propellant required? If no, why not?
Have the results of the model been factored into propellant design?
2. Higher output energetics. *The quantity of propellant is dependent on the required output. Use of higher output propellants may reduce the quantity of propellant required.*
Will higher output propellant allow for the reduction of total propellant? Why or why not?
Are higher output propellants available? List and describe as necessary.
Are higher output propellants under development? If yes, list and describe.
3. Alternative technology. *Approaches that improve reaction efficiency can reduce propellant required.*
Is it feasible to reduce the quantity of propellant with another technology?
Are technology enhancements for propellants available? If yes, list and describe.
Are technology enhancements for propellants under development? If yes, list and describe.
4. Binders. *If the propellant contains a binder, the use of an energetic binder may allow for a reduction in the total quantity of propellant required to achieve the same output.*
Does the propellant contain a non-energetic or energetic binder?
If non-energetic, is replacing the binder with an energetic binder feasible?
Are energetic binders under development for this propellant? If yes, list and describe.
III-B. Opportunity: Reduce energetic quantity in the fuze.

1.	**Optimization of quantity required.** *Computer models and simulations can be used to determine the optimal amount of energetics required to achieve desired performance.*
	Does a valid model to determine the optimal amount of energetics in the fuze exist?
	Has the model been run to determine the minimum energetics required? If no, why not?
	Have the results of the model been factored into the design of the fuze?
2.	**Higher output energetics.** *The quantity of energetics in the fuze is dependent on the required output. The use of higher output energetics may reduce the energetic quantity requirement.*
	Will higher output energetics allow for the reduction of total energetic content in the fuze train? Why or why not.
	Are higher output energetics available for use in this fuze train? List and describe as necessary.
	Are higher output energetics for use in this fuze train under development? If yes, list, describe, and provide an estimate of the time frame for implementation.
3.	**Alternative technology.** *Alternative technologies (e.g., electronics, higher reliability initiators, or multi-point initiators) have the potential to reduce the quantity of energetics in the fuze train.*
	Is it feasible to reduce fuze energetics with another technology? If yes, list.
	Are technology enhancements for fuze energetics available? If yes, list and describe as necessary.
	Are technology enhancements for fuze energetics under development? If yes, list, describe, and provide an estimate of the time frame for implementation.

III-C. Opportunity: Reduce energetic quantity of the main charge
1. Optimization of quantity required. *Computer models and simulations can be used to determine the optimal amount of energetics required to achieve desired performance.*
Does a valid model to determine the optimal amount of energetics in the main charge exist?
Has the model been run to determine the minimum energetics required? If no, why not?
Have the results of the model been factored into the design of the main charge?
2. Higher output explosives. *The quantity of main charge energetics is dependent on the required output. Reconfigured main charges using higher output explosives may reduce the explosive requirement.*
Will higher output energetics allow for the reduction of total energetic content in the main charge?
Are higher output energetics available for use in this main charge? List and describe as necessary.
Are higher output energetics for use in this main charge under development? If yes, list and describe.
3. Alternative technology. *Approaches such as enhanced initiation can potentially maintain or improve main charge results with less explosive.*
Is it feasible to reduce the quantity of main charge energetics with another technology?
Are technology enhancements for main charge energetics available? If yes, list and describe.
Are technology enhancements for main charge energetics under development? If yes, list and describe.
4. Binders. *If the main charge explosive contains a binder, the use of an energetic binder may allow for a reduction in the total quantity of energetic required to achieve the same output. This is due, in part, to the exothermic nature of the oxidation of an energetic binder.*
Does the main charge contain a binder?
If yes, is replacing the current binder with an energetic binder feasible to reduce the total quantity of explosive required? Explain as necessary.
Are energetic binders under development for this main charge? If yes, list and describe.

IV. Maximize the functional reliability of the munition to reduce the potential for contamination.

The following questions address opportunities for increasing the functional reliability of the munition through design, manufacturing, and maintenance of the quality of the munition as it is stored over time. All of the questions focus on factors that may impact the potential for contamination at training/test ranges. Contamination may result from incomplete combustion of propellant at the firing point or duds/low order detonations at the impact area.

The questions are grouped by Design; Manufacture; Load, Assemble, and Pack (LAP); and Shelf-life Management and Storage.

DESIGN. Achieve reliability improvements through munition design

IV-A. Opportunity: Design of propellant.
1. **Formulation/configuration.** *Contamination at the firing point may be reduced by using propellants that demonstrate improved combustion efficiency.*
Can improved propellant formulations be used in this munition? If no, why not?
Are improved propellant formulations available? If yes, list and describe as necessary.
Are improved propellant formulations under development? If yes, list, describe, and provide an estimate of the time frame for implementation.
2. **Coatings.** *Coating applied to propellant may provide for increased reliability due to the elimination of contamination from moisture or other degrading materials.*
Can coatings be applied to propellant to enhance the preservation of performance over time?
Are any coatings currently under consideration or in development? List.
3. **Binders.** *See item III.A.4. If the propellant contains a binder, the use of an energetic binder may improve reliability by decreasing dead spots in the energetic matrix.*
If the propellant contains a binder, is an energetic binder feasible to enhance reliability? If no, why not?
Are energetic binders available for implementation in this munition? List and describe.
Are energetic binders under development for this propellant? If yes, list, describe, and provide an estimate of the time frame for implementation.

IV-B. Opportunity: Design of fuze.
1. Formulation/configuration. *Changes in the formulation and configuration (e.g., number of critical interfaces, addition of sensitizers, length-to-diameter ratio)*
Are changes in the formulation or configuration of this fuze feasible? If no, why not?
What changes in formulation or configuration might result in improving the reliability of this fuze? List and describe.
2. Performance optimization. *A difference between design performance and actual performance may suggest a potential for an unacceptable dud/low order risk. Such differences may arise due to the difficulty in simulating the effect of launch loads on mechanical arming of the fuze (e.g., setback and rotation).*
Is there a difference between design and actual performance of the fuze in this munition?
If actual performance is worse, what is the source of performance degradation?
Can performance be enhanced to close the gap between design and actual performance? Describe.
3. Alternative technology. *Other technologies, such as electronics, have begun to replace the pyrotechnic functions within the fuze to improve reliability with fewer critical interfaces. Newer fuze technology can be employed to enhance reliability.*
Can alternative technologies be incorporated to improve reliability? If no, why not?
Are alternative technologies available to improve fuze reliability? If yes, list and describe.
Are alternative technologies to improve fuze reliability under development? If yes, list, describe, and provide an estimate of the time frame for implementation.
4. Redundancy. *Functional reliability may be greatly enhanced by redundant fuze functions (e.g., use of two independent initiation channels in place of a single channel, use of backup fuzes).*
What are areas of highest functional risk of the fuze?
In what areas would component redundancy reduce this risk? List and describe.
Are redundant capabilities available? If yes, list and describe.
Are redundant capabilities under development? If yes, list, describe and provide an estimate of the time frame for implementation.

5. Protection from contamination and damage. *Adequate protection of the fuze energetics from contamination by moisture or volatiles may enhance the performance and reliability of the fuze. For example, hermetic sealing will provide long-term protection.*
How are the individual fuze elements and overall fuze train protected from contamination and damage? List for each element.
Is the use of improved sealing or other protective technologies feasible for this fuze? If yes, provide recommendations.

IV-C. Opportunity: Design of main charge.
1. Formulation/configuration. *Alternative main charge designs that involve changed formulations (e.g., use of plasticized energetics) or configurations (e.g., shaping of charge, separately-loaded charge) may result in improved main charge reliability.*
Are alternative formulations or configurations of the main charge energetic feasible for this munition?
Are alternative formulations or configurations of the main charge energetic available? List.
Are alternative formulations or configurations of the main charge under development? If yes, list, describe, and provide an estimate of the time frame for implementation.
2. Coatings. *Explosive coatings may be used to facilitate processing and/or add desensitizers to the charge. (Note—the same technology may also have application to seal the explosive so that, in the event of a dud or low-order event, the explosive is less likely to be an environmental concern.)*
Is a coated explosive feasible in this main charge? If no, why not?
Are suitable coated explosives available? List and describe.
Are coated explosives under development for this main charge? If yes, list, describe, and provide an estimate of the time frame for implementation.
3. Binders. *See item III.C.4. If the main charge explosive contains a binder, the use of an energetic binder may improve reliability by decreasing dead spots in the energetic matrix.*
If the main charge explosive contains a binder, is an energetic binder feasible to enhance reliability? If no, why not?
Are energetic binders available for implementation in this munition? List and describe.
Are energetic binders under development for this main charge? If yes, list, describe, and provide an estimate of the time frame for implementation.

IV-D. Opportunity: Integrated platform design.
1. **Performance optimization.** *Computer models, simulations, and similar analyses can be used to enhance the reliability of the integrated munition.*
Does a means to predict or model the performance of the munition exist? If so, list and describe.
Have such predictions or models been used to evaluate the performance of this munition? If so, what are the results/findings?
Have the results/findings been factored into the design of the munition? If no, why not?
2. **Materials of construction.** *Material incompatibilities may accelerate decomposition or degradation of energetic materials. For example, outgassing from elastomeric seals may degrade the booster pellet.*
List and characterize materials of construction.
Is there a potential for material incompatibilities to accelerate decomposition or degradation of energetic materials? List and describe.
If so, are material substitutions feasible to eliminate such incompatibilities? List and describe.
3. **Energetic interfaces.** *The characteristics of interfaces between the energetics may impact the overall reliability of the explosive train. For example, gap distance, type and grain structure of metal discs that separate the energetics, differences in velocity of detonation, and geometry can all affect reliability.*
List and characterize all energetic interfaces.
Have tolerance stack-ups been considered? If no, why not?
Which of these might potentially affect the reliability of the explosive train? List and describe.
Can any of these interfaces be eliminated or modified to reduce their effect? List and describe.
4. **Variability control.** *Cpk is a statistical measure of manufacturing process variability. This variability is directly affected by the design of the item. A design should consider that a Cpk of 1.33 or greater is desirable for product reliability. For example, a design that specifies the use of a glued joint may result in a low Cpk (i.e., high process variability), whereas a push-and-twist lock joint may permit a higher Cpk (i.e., low process variability).*
What is the Cpk of the integrated platform?
Can increased Cpk be attained by alternative designs? If no, why not?

IV-E. Opportunity: Design of packaging.
1. **Protection from contamination and damage.** *Packaging has an important responsibility to protect the munition or munition components from possible damage during handling and storage, thereby ensuring its reliability during use.*
What packaging systems are used for the munition and its components? List and describe.
Has packaging proven to be adequately protective during product handling? If no, describe any problems or concerns.
Has packaging proven to be adequately protective throughout the established shelf life of the munition? If no, describe.
Are there more protective materials or improved methods that might be considered for packaging? List and describe.
2. **Prediction of performance.** *Smart packaging may be useful to determine the condition of the munition while in storage. For example, it may be possible that packaging could be designed to sense the presence of degradation byproducts.*
Is the use of smart packaging feasible? If no, why not?
What characteristics of the munition or its components would be indicative of degradation/deterioration of the munition? List and describe.
Is smart packaging available? List and describe.
Is smart packaging under development? List, describe, and provide an estimate of the timeframe for implementation.

MANUFACTURE. Achieve reliability improvements in the manufacturing process

IV- F. Opportunity: Manufacture of propellant.
1. **Production demand fluctuations.** *Some production processes may be more impacted by starts, stops, and production rate variations as a function of demand. Such variations might, in turn, affect product reliability.*
Do production demand fluctuations negatively impact propellant quality?
What processes are affected by production demand fluctuations and what are the implications? List and describe.
2. **Production discontinuities.** *Shift changes and other discontinuities may impact component or munition variability and reliability.*
Is propellant quality affected by processing discontinuities such as shift changes?
What processes are affected by discontinuities and what are the implications? List and describe.
3. **Product movement.** *Movement of product from one workstation to another can increase its vulnerability to contamination or damage and thereby threaten its reliability.*
At what point(s) in the process is the product moved from one workstation to another? List and describe.
Is it feasible to optimize product movement to enhance product reliability? If no, why not?
4. **Variability analysis.** *Cpk is a statistical measure of manufacturing process variability. A process should be capable of achieve a Cpk of 1.33 or greater to ensure product reliability. For example, variability can be minimized by using direct measurements of primary variables instead of derived measurements.*
What is the Cpk of the propellant?
Can increased Cpk be attained by alternative designs? If no, why not?
5. **Processing of raw materials.** *Volatiles in the raw materials can desensitize the propellant thereby decreasing reliability.*
In which of the raw materials are volatiles present? List.
Can volatiles be minimized at the bulk level through improved drying techniques? Describe.

6.	**Raw material quality.** *Raw materials may be accepted based on certification alone. Validation testing at the point of receipt may improve reliability by ensuring that critical aspects of raw materials meet specifications. Lot-to-lot product variabilities can be minimized by control and management of raw materials and by process improvements.*
	Does the process use certification acceptance for raw materials? List
	Is certification acceptance for these materials based on threshold criteria (i.e., go/no go) or actual values?
	If yes, can point-of-use testing be implemented for acceptance where certification acceptance is currently used? If no, why not?
	Is raw material acquisition adequately managed and controlled to minimize product variabilities? If no, why not?
	Can mix variability be reduced by using purer raw materials? If no, why not?
7.	**Production methods.** *Included solvents and moisture in the propellant components can ultimately cause desensitization and loss of reliability.*
	What propellant components used in this munition are likely to be at risk for included solvents and/or moisture intrusion? List and describe.
	Can included-solvents and moisture be minimized through improved separation and/or drying techniques? If yes, describe.
8.	**Personnel Turnover.** *Interrupted or sporadic production demand can result in employee turnover. Furthermore, the use of union workers may result in different crews being assigned to work on the production line each week. Training and standard operating procedures are crucial to ensure that workers produce consistent products.*
	Are standard operating procedures posted at each workstation?
	Have standard operating procedures been updated recently?

IV-G. Opportunity: Manufacture of fuze
1. **Production demand fluctuations.** *Some production processes may be more impacted by starts, stops, and production rate variations as a function of demand. Such variations might, in turn, affect product reliability.*
Do production demand fluctuations negatively impact component or fuze quality?
What processes are affected by production demand fluctuations and what are the implications? List and describe.
2. **Production discontinuities.** *Shift changes and other discontinuities may impact component or munition variability and reliability.*
Is component or fuze quality affected by processing discontinuities such as shift changes?
What processes are affected by discontinuities and what are the implications? List and describe.
3. **Product movement.** *Movement of product from one workstation to another can increase its vulnerability to contamination or damage and thereby threaten its reliability.*
At what point(s) in the process is the product moved from one workstation to another? List and describe.
Is it feasible to optimize product movement to enhance product reliability? If no, why not?
4. **Variability analysis.** *Cpk is a statistical measure of manufacturing process variability. A process should be capable of achieve a Cpk of 1.33 or greater to ensure product reliability. For example, variability can be minimized by using direct measurements of primary variables instead of derived measurements.*
What is the Cpk of the fuze?
Can increased Cpk be attained by alternative designs? If no, why not?
5. **Protection from contamination and damage.** *Contamination of fuze train interfaces during the manufacturing process can negatively affect their performance and munition reliability. Contaminants might include skin oils, workstation items, and packaging residues.*
Can contamination be imparted into the fuze train interfaces? List and describe.
6. **Static control.** *The presence of static electricity in the manufacturing process may have a negative impact on the electronic and energetic components of the fuze and thereby affect munition reliability.*
Is the level of static control consistent with the susceptibility of the components being assembled?

7.	**Raw material quality.** *Raw materials may be accepted based on certification alone. Validation testing at the point of receipt may improve reliability by ensuring that critical aspects of raw materials meet specifications. Chemical and material incompatibilities may be an issue if the fuze elements came from a variety of manufacturers. In addition, cumulative effects may diminish the tolerance window over time.*
	Does the process use certification acceptance for raw materials? List
	Is certification acceptance for these materials based on threshold criteria (i.e., go/no go) or actual values?
	If yes, can point-of-use testing be implemented for acceptance where certification acceptance is currently used? If no, why not?
	Are the fuze elements assembled from parts made by a number of different subcontractors?
	Has it been shown that the parts are chemically compatible to the degree necessary to minimize the potential for desensitization of energetics through deterioration?
	Does the assembled fuze have the necessary cumulative reliability at tolerance extremes?
8.	**Glues, Potting, and adhesives.** *Issues associated with the use of glues or adhesives include the potential for contamination of critical interfaces and the quality of application as driven by pot life of the adhesive, surface preparation, and under- or over-application.*
	Are glues or adhesives used in the fuze train assembly? If so, where?
	Can the evacuation of air cause glue to be forced into a critical interface?
	How is the pot life of glue or adhesive controlled?
	How is surface preparation controlled for the application of glues or adhesives?
	How is application quantity controlled?
	Can the use of glues or adhesives be replaced by more definitive sealing methods such as laser or projection welding? Describe.

9. Validation of fuze. *Where a blind assembly exists, a method is needed to verify the presence, quantity, order, and orientation of all fuze components.*	
	How is the fuze validated for presence, quantity, order, and orientation of components? List and describe.
	Are methods used for validation adequate to ensure reliability?
	Can improved validation methods be employed? If no, why not?
10. Personnel Turnover. *Interrupted or sporadic production demand can result in employee turnover. Furthermore, the use of union workers may result in different crews being assigned to work on the production line each week. Training and standard operating procedures are crucial to ensure that workers produce consistent products.*	
	Are standard operating procedures posted at each workstation?
	Have standard operating procedures been updated recently?

IV-H. Opportunity: Manufacture of main charge.
1. Production demand fluctuations. *Some production processes may be more impacted by starts, stops, and production rate variations as a function of demand. Such variations might, in turn, affect product reliability.*
Do production demand fluctuations negatively impact explosive quality?
What processes are affected by production demand fluctuations and what are the implications? List and describe.
2. Production discontinuities. *Shift changes and other discontinuities may impact component or munition variability and reliability.*
Is explosive quality affected by processing discontinuities such as shift changes?
What processes are affected by discontinuities and what are the implications? List and describe.
3. Product movement. *Movement of product from one workstation to another can increase its vulnerability to contamination or damage and thereby threaten its reliability.*
At what point(s) in the process is the product moved from one workstation to another? List and describe.
Is it feasible to optimize product movement to enhance product reliability? If no, why not?
4. Variability analysis. *Cpk is a statistical measure of manufacturing process variability. A process should be capable of achieve a Cpk of 1.33 or greater to ensure product reliability. For example, variability can be minimized by using direct measurements of primary variables instead of derived measurements.*
What is the Cpk of the explosive?
Can increased Cpk be attained by alternative designs? If no, why not?
5. Processing of raw materials. *Volatiles in the raw materials can desensitize the energetic product thereby decreasing reliability.*
In which of the raw materials are volatiles present? List.
Can volatiles be minimized at the bulk level through improved drying techniques? Describe.

6. Raw material quality. *Raw materials may be accepted based on certification alone. Validation testing at the point of receipt may improve reliability by ensuring that critical aspects of raw materials meet specifications. Lot-to-lot product variabilities can be minimized by control and management of raw materials and by process improvements.*
Does the process use certification acceptance for raw materials? List
Is certification acceptance for these materials based on threshold criteria (i.e., go/no go) or actual values?
If yes, can point-of-use testing be implemented for acceptance where certification acceptance is currently used? If no, why not?
Is raw material acquisition adequately managed and controlled to minimize product variabilities? If no, why not?
Can mix variability be reduced by using purer raw materials? If no, why not?
7. Production methods. *Changes or improvements to production methods may be candidates for improving the reliability of the main charge. Areas of emphasis include processes that reduce quantities of included solvents and moisture and improve the overall consistency of the product.*
Are processes used to reduce solvents, eliminate moisture inclusion, and ensure a uniform product density adequate for this main charge? If no, list and describe.
Are there opportunities for improving the reliability of the main charge through employing or improving processes that reduce solvents, eliminate moisture, and minimize density gradients in the product? List and describe.
8. Personnel Turnover. *Interrupted or sporadic production demand can result in employee turnover. Furthermore, the use of union workers may result in different crews being assigned to work on the production line each week. Training and standard operating procedures are crucial to ensure that workers produce consistent products.*
Are standard operating procedures posted at each workstation?
Have standard operating procedures been updated recently?

IV-I. Opportunity: Manufacture of metal parts and other hardware.
1. Production demand fluctuations. *Some production processes may be more impacted by starts, stops, and production rate variations as a function of demand. Such variations might, in turn, affect product reliability.*
Do production demand fluctuations negatively impact component or munition quality?
What processes are affected by production demand fluctuations and what are the implications? List and describe.
2. Production discontinuities. *Shift changes and other discontinuities may impact component or munition variability and reliability.*
Is component or munition quality affected by processing discontinuities such as shift changes?
What processes are affected by discontinuities and what are the implications? List and describe.
3. Product movement. *Movement of product from one workstation to another can increase its vulnerability to contamination or damage and thereby threaten its reliability.*
At what point(s) in the process is the product moved from one workstation to another? List and describe.
Is it feasible to optimize product movement to enhance product reliability? If no, why not?
4. Variability analysis. *Cpk is a statistical measure of manufacturing process variability. A process should be capable of achieve a Cpk of 1.33 or greater to ensure product reliability. For example, variability can be minimized by using direct measurements of primary variables instead of derived measurements.*
What is the Cpk of the hardware?
Can increased Cpk be attained by alternative designs? If no, why not?
5. Raw material quality. *Raw materials may be accepted based on certification alone. Validation testing at the point of receipt may improve reliability by ensuring that critical aspects of raw materials meet specifications.*
Does the process use certification acceptance for raw materials? List
Is certification acceptance for these materials based on threshold criteria (i.e., go/no go) or actual values?
If yes, can point-of-use testing be implemented for acceptance where certification acceptance is currently used? If no, why not?

6. **Compatibility with energetic.** *All materials used in the manufacture of metal parts and other hardware must be compatible with the energetic to prevent its degradation over time.*
What are the materials used in the manufacture of metal parts and other hardware? List.
Have the corrosion protection materials used been evaluated to ensure their compatibility with the energetic? If no, why not.
Are all the materials used compatible with energetics? Describe those that are not.
7. **Protection from contamination and damage.** *Contamination of the metal parts and other hardware can contribute to material incompatibility and other detrimental affects that can impact reliability.*
Are cleaning agents proven to be capable of removing lubricants and machining coolants? If no, why not?
Are all cleaning agents removed by rinse? If no, why not?
Are parts protected from contamination or damage from workers or the workplace environment? If no, why not?
After cleaning, is the part susceptible to contamination? If yes, how?
8. **Personnel Turnover.** *Interrupted or sporadic production demand can result in employee turnover. Furthermore, the use of union workers may result in different crews being assigned to work on the production line each week. Training and standard operating procedures are crucial to ensure that workers produce consistent products.*
Are standard operating procedures posted at each workstation?
Have standard operating procedures been updated recently?

LAP. Achieve munition reliability improvements in the LAP process.

IV-J. Opportunity: LAP facilities
1. **Housekeeping.** *Cleanliness and order can minimize the potential for contamination and maximize visual control (e.g., allows for clear line-of-sight to critical processes, allows for increased operator awareness).*
Are facilities at a level of cleanliness and order to avoid operator error and contamination? If no, describe conditions where cleanliness and order could be improved.
2. **Environmental controls.** *Adequate control of HVAC and other workplace environmental characteristics can help to ensure product quality and consistency and eliminate potential contaminants such as dust and moisture.*
Are there any known problems with environmental controls? List and describe.
Are controls adequate to ensure consistent product quality? If no, why not?

IV-K. Opportunity: LAP operations
1. **Loading processes.** *Loading and consolidating processes determine the density of the energetic, which, in turn, influences the output, and sensitivity of the munition. Uniform density is important to achieve consistent performance and reliability.*
What loading and consolidating processes are used? List and describe.
Are loading and consolidating processes designed to achieve uniform density and minimize the potential for bridging or other gap-forming conditions?
Are alternative loading and consolidating processes feasible? List and describe.
2. **Optimization of process steps.** *Unnecessary process steps increase the vulnerability of the munition to contamination.*
What are the process steps performed when the munition is vulnerable to contamination? List.
Can any or all of these steps be eliminated? List and describe.
3. **Automation.** *Automation may simplify process control and eliminate human variability.*
What processes are not automated? List.
Can any of these non-automated processes, be automated? If no, why not?
Is it feasible to increase the degree of repeatable automation in energetic operations where rate functions and dwell parameters are critical?
4. **Process flow.** *The order of assembly will influence the product consistency and, hence, reliability. For example, the order of assembly will affect the stack-up of tolerances. Different materials applied in different order will yield a different result.*
Is there an established order of assembly? If no, why not?
Is the established order consistently applied? If no, why not?
Has the order of assembly been optimized for maximum performance? If no, why not?

5. Quality assurance. *Quality should be verified at several stages in the LAP process in order to ensure product quality and performance.*
Are energetic subassemblies tested prior to the LAP process to confirm quality? If no, why not?
Does process verification take place as the fabrication process proceeds?
Is in-process verification feasible?
Are Acceptance Quality Levels (AQL) used to accept the reliability of the LAP process?
Are there procedures that may be employed to approach 100% reliability? List.

SHELF-LIFE MANAGEMENT AND STORAGE. Achieve reliability improvements through changes in shelf-life management and storage.

IV-L. Opportunity: Storage of munition components.
1. **Age.** *Specified shelf life may not be valid as a result of munition variabilities.*
Is there a known relationship between age of components and their performance? Describe.
Are components monitored for shelf lives or age in a training environment?
2. **Storage.** *How a munition is stored (climate and handling) can affect its performance and reliability.*
Is munition performance sensitive to storage conditions?
If so, are there opportunities to modify the design to reduce this sensitivity? List.
Do actual storage conditions correspond to those for which the munition was designed? If no, why not?
Do different materials and munitions share the same storage space?
Do material incompatibilities introduce concerns with aging and reliability? Describe.
Are storage management procedures specified for this munition? Describe.
Are storage data collected for use in predicting unreliability? Describe.

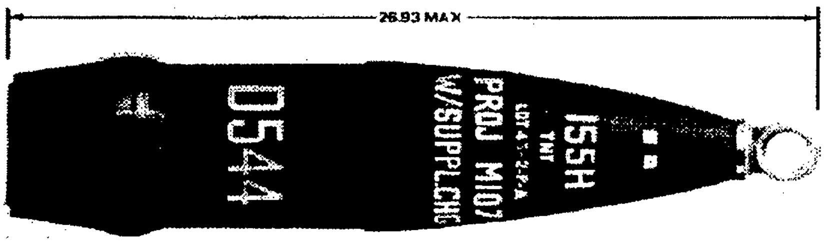
V. Minimize the environmental impacts on the range

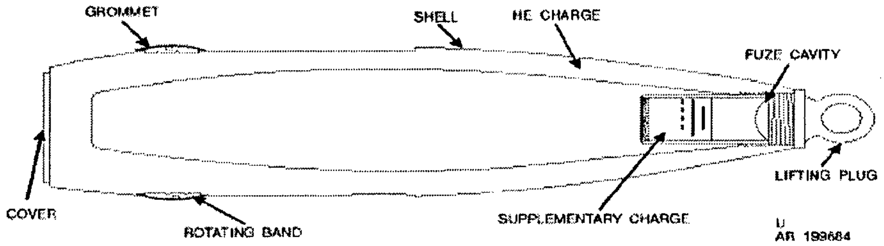
The following questions address opportunities for making changes to the munition to reduce contamination on training/testing ranges caused by low order detonations or duds.

V-A. Opportunity: Prevent exposure of energetic to environment
1. **Isolation of energetic from the environment.** *If a round is incompletely detonated, isolation of the energetic may minimize the potential for contamination. Means of isolation may include methods to encapsulate the energetic, use of strengthened containment structures, and use of more corrosion-resistant materials.*
Is it feasible to provide for a means to ensure that the energetic does not come into contact with the environment in the event of an incomplete detonation or dud. If yes, list and describe.
2. **Location of incompletely detonated munitions for removal.** *If a round is incompletely detonated, improved methods for recording and locating the round would facilitate its removal from the range and, in turn, remove the potential for further contamination.*
Is it feasible to incorporate technologies in the munition to facilitate its location and recovery? If yes, list and describe.
3. **Prevention of sympathetic detonations.** *Sympathetic detonations compound the potential for spread of contamination. Reducing the potential for sympathetic detonations would have a positive environmental effect.*
Is it feasible to incorporate into the munition some means to prevent the occurrence of a sympathetic detonation? If yes, describe.

Appendix B
M107 155-mm HE Projectile

PROJECTILE, 155-MILLIMETER: HE, M107 (NORMAL AND DEEP CAVITY)





Type Classification:

Deep Cavity: Std OTCM 36841, dtd 1958.
Normal Cavity: Std OTCM 36841, dtd 1958.

Use

This projectile is fired from 155mm howitzers and is used for blast effect, fragmentation, and mining.

Description:

The projectile is a hollow steel shell filled with 14.6 pounds of TNT or 15.4 pounds of Composition B. The shape is ogival with a boat-tail for aerodynamic efficiency. A supplementary charge of 0.3 lb TNT is contained in an aluminum liner in the deep fuze cavity. A threaded lifting plug closes the fuze cavity at the nose of the projectile for handling and storage. Point detonating, time or proximity fuzes may be used with this projectile. A rotating band encircles the shell casing near the base and is protected by a grommet before loading. A steel plate (base cover) is welded over the base to prevent entry of hot propellant gases into the projectile interior.

Functioning:

When the weapon is fired, the burning propellant charge generates rapidly expanding gases to propel the projectile through the barrel with the velocity required to reach the target. The soft alloy rotating band engages the barrel rifling to impart spin to the projectile for stability in flight. If a point detonating fuze or time fuze is employed, the fuze detonates the supplementary charge on impact (PD) or after the preset time (MT), and the supplementary charge detonates the projectile filler. When a proximity fuze is used, detonation occurs on approach to the target (proximity action). The proximity fuze contains its own booster element to initiate the warhead filler.

Difference Between Models:

155mm HE Projectile M107 (Normal Cavity) has a shallower fuze receptacle.

Tabulated Data:

Zone	Weight Zones Loaded Projectile (w/o fuze, w/o plug) Pounds Over	Up to & Incl	Marking
2	90.0	91.3	[•] [•]
3	91.1	92.4	[•] [•] [•]
4	92.0	93.7	[•] [•] [•] [•]
5	93.3	94.6	[•] [•] [•] [•] [•]

Complete round:
- Type ------------------------------ HE
- Length w/lifting plug --------- 26.93 in. max
- Length w/o lifting plug ------ 23.89 in.
- Cannon used with ------------- M1, M1A1, M1A2, M45, M126, M126A1, M185, XM199

Projectile:
- Body material ----------------- Forged steel
- Color ---------------------------- Olive drab w/yellow markings

Filler and weight:
- TNT ------------------------------ 14.6 lb
- Comp B -------------------------- 15.4 lb

Primers:
- For cannon:
- M45, M126, M126A1, M199, and M185 -------------- M82
- M1, M1A1 ---------------------- MK2A4
- Propelling charges ------------ M3, M3A1, M4A1, M4A2, M119/M119A1
- Fuzes ----------------------------- PD: M557, M78 series; M739 series; MK399 MOD 1; MTSQ: M564, M582 series; Prox: M728, M732 series, ET: M767

Temperature Limits:

Firing:
- Lower limit -------------------- -65°F
- Upper limit -------------------- +145°F

Storage:
- Lower limit -------------------- -80°F (for periods not more than 3 days)
- Upper limit -------------------- + 160°F (for periods not more than 4 hr/day)

*Packing ------------------------ 8 projectiles on pallet

*Pallet:
- Weight --------------------------- 797 lb
- Dimensions -------------------- 27-1/8 x 13-5/8 x 32 in.
- Cube ------------------------------ 6.8 cu ft

*NOTE See DOD Consolidated Ammunition Catalog for complete packing data including NSN's.

Shipping and Storage Data:

- Quantity-distance class --------- (18) 1.1
- Storage compatibility group -- D
- DOT shipping class -------------- A
- DOT designation . . . . EXPLOSIVE PROJECTILES

DODAC:
- Deep cavity --------------------- 1320-D544
- Normal cavity ------------------ 1320-D571
- Assembly Dwg No.
  - Deep cavity ------------------ 9216352
- UNO serial number ------------- 0168
- UNO proper shipping name --- Projectiles

Ballistics:

Cannon M1, M1A1, M45:

Charge	Muzzle Velocity (m/s)	Max Range (m)	Elevation (mil)
1, M3, green bag	207.3	3900	774.4
2, M3, green bag	234.7	4800	698.6
3, M3, green bag	268.2	6100	729.2
4, M3, green bag	310.9	7800	749.6
5, M3, green bag	371.9	9700	760.7
3, M4A1, white bag	274.3	6300	702.7
4, M4A1, white bag	316.4	8000	729.9
5, M4A1, white bag	374.6	9700	720.6
6, M4A1, white bag	463.3	12000	759.8
7, M4A1, white bag	563.9	14600	740.8

Ballistics: (cont.)

Cannon M126/M126A1:

Charge	Muzzle Velocity (m/s)	Max Range (m)	Elevation (mil)
1, M3A1, green bag	207.3	3900	729.2
2, M3A1, green bag	236.2	4900	710.1
3, M3A1, green bag	275.8	6500	739.3
4, M3A1, green bag	317.0	8200	744.1

Cannon M126/M126A1:

Charge	Muzzle Velocity (m/s)	Max Range (m)	Elevation (mil)
5, M3A1, green bag	374.9	9800	743.2
3, M4A2, white bag	269.7	6200	700.7
4, M4A2, white bag	313.9	8000	700.8
5, M4A2, white bag	373.4	9800	778.8
6, M4A2, white bag	461.8	12000	746.2
7, M4A2, white bag	562.4	14600	772.5

Cannon M185:

Charge	Muzzle Velocity (m/s)	Max Range (m)	Elevation (mil)
1, M3A1, green bag	211.8	4000	673.6
2, M3A1, green bag	237.7	5000	722.4
3, M3A1, green bag	277.4	6500	690.4
4, M3A1, green bag	318.5	8300	760.9
5, M3A1, green bag	374.9	9800	717.2
3, M4A2, white bag	292.6	7200	734.9
4, M4A2, white bag	336.8	8900	736.8
5, M4A2, white bag	393.2	10300	756.1
6, M4A2, white bag	475.5	12400	758.4
7, M4A2, white bag	565.4	14800	760.3
8, M119/ M119A1	684.3	18100	781.5

Cannon M199:

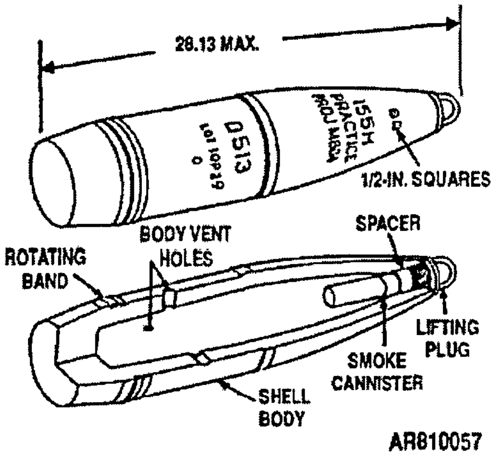
Charge	Muzzle Velocity (m/s)	Max Range (m)	Elevation (mil)
1, M3A1, green bag	212.8	4000	673.6
2, M3A1, green bag	239.8	5000	722.4
3, M3A1, green bag	280.8	6500	690.4
4, M3A1, green bag	322.9	8300	760.9
5, M3A1, green bag	380.1	9800	717.2
3, M4A2, white bag	296.5	7200	734.9
4, M4A2, white bag	340.9	8900	736.8
5, M4A2, white bag	398.0	10300	756.1
6, M4A2, white bag	482.0	12400	758.4
7, M4A2, white bag	574.3	14800	760.3
8, M119/ M119A1	684.3	18100	781.5

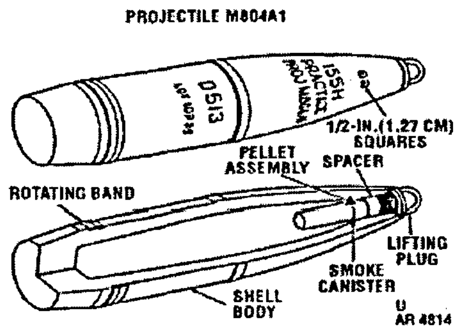
References:

AMC-P 700-3-3
SB 700-20
TM 9-1025-200-12&P
TM 9-1300-251-20
TM 9-2350-311-10
TM 9-2350-314-10

Appendix C
M804/M804A1 155-mm Training Practice Projectile

PROJECTILE, 155 MILLIMETER: PRACTICE, M804 AND M804A1





lassification:

04: Standard MSR 01816002
04A1. Standard: dtd December 91.

5mm, M804/M804A1 projectile is used in place of 107, HE projectile for training in indirect fire of howitzers. The M804/M804A1 projectile s a smoke canister In the fuze well, which s for a visual determination of functioning. It can ɟ in training at less cost than an M107 projectile, the blast and fragmentation which accompany ıing of an M 107.

ɔtion:

804/M804A1 is similar in weight and external ration to the M107 HE projectile. The body of the le is a thick walled hollow steel shell, which s no filler. A smoke canister, which has the same l appearance as a supplementary charge, is ed in the deep fuze cavity. A threaded lifting plug the fuze cavity at the nose of the projectile for g and storage. A rotating band encircles the shell near the base and a steel base plate is welded e base to prevent entry of propellant gases into erior. The rotating band is protected during nt and handling by a plastic grommet installed at ɜ of manufacture.

Functioning:

The projectile fitted with a PD, MTSQ, or PROX fuze is loaded into the weapon with propelling charge and primer. When the weapon is fired, the burning propellant charge generates rapidly expanding gases to propel the projectile through the barrel with the velocity required to reach the target The soft alloy rotating band engages the barrel rifling to Impart spin to the projectile for flight stability. Fuze functioning detonates the smoke canister. The flash and smoke escape, producing a visual report. This enables the observer to spot the location of the projectile functioning.

Difference Between Models:

The smoke canister in the M804 is smaller (190g smoke composition) and is contained in an aluminum liner. The smoke canister in the M804A1 is larger (450g smoke composition) and is contained in a steel cup. In addition, the smoke canister in the M804A1 contains an explosive 20g pellet.

The body of the M804 contains four holes, 90 degrees apart, whereas the M804A1 doesn't have any.

For storage, handling, and transportation the M804A1 must have the cover support over the lifting plug to prevent the rub off action from the pallet cover.

Tabulated Data:

WEIGHT ZONES
Loaded Projectile (w/o fuze, w/o plug)
Pounds

Zone	Over	Up to & Incl	Marking
2	90 0	91.3	⊡ ⊡
3	91.1	92.4	⊡ ⊡ ⊡
4	92.0	93.7	⊡ ⊡ ⊡ ⊡
5	93.3	94.6	⊡ ⊡ ⊡ ⊡ ⊡

Complete Round.
- Type....................Practice
- Length w/lifting plug..............28.13 in max
- Length w/o lifting plug...........23.80 in max
- Cannon used with................M1, M1A1, M1A2, M45, M126, M126A1, M185, M199, M284

Projectile. M804
- Body material.......................Forged steel
- Color Blue w/white marking and brown band

Projectile M804A1
- Body material.......................Forged steel or cast iron
- Color.................................Blue w/white marking and yellow band

Smoke Canister:
- M804.
  - Length...........................2.57 in.
  - Diameter.........................1.79 in.
  - Weight...........................0.43 lb
  - Filler: weight....................190g (smoke comp)
- M804A1:
  - Length...............................6.51 in.
  - Diameter.............................1.75 in. max
  - Comp A5............................20g
  - Filler weight.........................450g (smoke comp)

Canister Composition for M804 and M804A1:
- Zinc dust.............................40%
- Potassium perchlorate..........20%
- Potassium nitrate.................20%
- Aluminum (Atomized)...........20%

Pellet Assembly. M804A1
- Length................................0 53 in. max
- Diameter.............................1.730 in max
- Explosive:
  - Weight 20g

Marking (Black)

THIS END UP
CANISTER, SMOKE'
SW-522 SW-522 SW-522
FOR ARTILLERY PROJECTILE

Primers.
- For cannon:
  - M45, M126, M 126A1, M199, M185, and M284....M82
  - M1,M1A1, M1A2.............M198, M109, M109A1, M109A2, M109A3, M109A4, M109A5, M109A6, M114A1, M114A2

Propelling charges ....M3 Series, M4 Series, M119 Series

Fuzes.....................................PD. M557, M739 Series, MTSQ. M564 M582, PROX: M732, ET: M767

Temperature Limits:

Firing:
- Lower limit ....-60°F (-51°C)
- Upper limit . ...+145°F (+62.8°C)

Storage:
- Lower limit ....-80°F (-62.2°C) (for periods not more than 3 days)
- Upper limit...............................+160°F (+71.1°C) (for periods not more than 4 hr/day)

Packing Data:

*Packing	8 projectiles on pallet
*Pallet:	
Weight	780 lb
Dimensions	27-1/2 x 14-1/8 x 30-7/16 in.
Cube	6.8 cu ft

*NOTE: See DOD Consolidated Ammunition Catalog for complete packing data including NSN's. A cover support is necessary to protect the top of each M804A1 projectile while in the pallet. The cover supports are considered part of the pallet.

Shipping and Storage Data:

UNO serial number	0362
DOT hazard class/ division/SCG	1.4G
DOT class	Class C Explosives
DOT marking	CARTRIDGE, PRACTICE AMMUNITION
DOT label	EXPLOSIVE C
DODAC	1320-D513
UNO serial number	0362
UNO proper shipping name	Ammunition practice
M804 Assembly Dwg. No.	9331794
M804A1 Assembly Dwg. No.	12913926

Limitations:

Charge 1 must not be fired in the M199 cannon because of stickers.

Ballistics:

Cannon M1, M1A1, M45:

Charge	Muzzle Velocity (mps)	Max Range (m)	Elevation (mi)
1, M3, green bag	207.3	3900	774.4
2, M3, green bag	234.7	4800	698.6
3, M3, green bag	268.2	6100	729.2
4, M3, green bag	310.9	7800	749.6
5, M3, green bag	371.9	9700	760.7
3, M4A1, white bag	274.3	6300	702.7
4, M4A1, white bag	316.4	8000	729.9
5. M4A1, white bag	374.6	9700	720.6

Cannon M126/M126A1, M1A2:

Charge	Muzzle Velocity (mps)	Max Range (m)	Elevation (mi)
1, M3A1, green bag	207.3	3900	729.2
2, M3A1, green bag	236.2	4900	710.1
3, M3A1, green bag	275.8	6500	739.3
4, M3A1, green bag	317.0	8200	744.1
5, M3A1 green bag	374.9	9800	743.2
3. M4A2, white bag	269.7	6200	700.7
4, M4A2, white bag	313.9	8000	700.8
5, M4A2, white bag	373.4	9800	778.8

Cannon M185:

Charge	Muzzle Velocity (mps)	Max Range (m)	Elevation (mi)
1, M3A1, green bag	208	3900	719.6
2, M3A1 green bag	236	4900	735.1
3. M3A1, green bag	276	6500	725.8
4, M3A1 green bag	316	8100	719.3
5, M3A1 green bag	376	9900	724.0
3, M4A2, white bag	297	7300	700.3
4, M4A2 white bag	337	8800	770.5
5, M4A2 white bag	397	10300	728.7
6, M4A2 white bag	474	12200	726.6
7, M4A2, white bag	568	14700	756.8
8, M119 M119A1	684	18100	804.1
7, M119A2, red bag	686	18154	804.1

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ACRONYMS

5S	Sort, Set in Order, Shine, Standardize, Sustain
ACSIM	Assistant Chief of Staff for Installation Management
AEC	Army Environmental Center
AFCEE	Air Force Center for Environmental Excellence
Akardit II	Methyl Diphenyl Urea
AO	American Ordnance
AQL	Acceptable Quality Level
ARDEC	Armament Research Development and Engineering Center
ARSIC	Army Range Sustainment Integration Council
CHPPM	Center for Health Promotion and Preventive Medicine
DANPE	1,5-diazido-3-nitrazapentane
DEPSECDEF	Deputy Secretary of Defense
DoD	Department of Defense
EED	Electro-Explosive Device
EPA	Environmental Protection Agency
EQT	Environmental Quality Technology
ERDC	Engineer Research and Development Center
FEFO	Bis-(2-fluoro-2,2-dintiroethyl)formal
FOCIS	FOCIS Associates, Inc.
FY	Fiscal Year
G-3	Office of the Deputy Chief of Staff for Operations and Plans
GAP	Glycidal azide polymer
GAO	General Accounting Office
GAT	Green Armaments Technology
GPS	Global Positioning Satellite
HE	High Explosive
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HNS	Hexanitrostilbene
HQDA	Headquarters Department of the Army
HVAC	Heating, Ventilation, and Air Conditioning
IMA	Installation Management Agency
IM	Insensitive Munitions
ITAM	Integrated Training Area Management
LAP	Load, Assemble, and Pack
LX-14	Livermore Explosive 14 (95.5% HMX, 4.5% estane)
MACOM	Major Command
MACS	Modular Artillery Charge System
MAP	Munitions Action Plan
MDF	Mild Detonating Fuze
MIDAS	Munitions Items Disposition Action System
MOFA	Multi-Option Fuze for Artillery
MTSQ	Mechanical Timed Super Quick
N45	Chief of Naval Operations Environmental Readiness Division
MMR	Massachusetts Military Reservation

ACRONYMS
(continued)

ODCSOPS	Office of the Deputy Chief of Staff for Operations and Plans
ODEP	Office of the Director Environmental Programs
OEESCM	Operational and Environmental Executive Steering Committee for Munitions
PAM	Penetrating Augmented Munition
PAP	Propulseur d'Appoint á Poudre
PBX	Plastic-Bonded Explosive
PBX9404	PBX formulation (93% HMX, 6.5% nitrocellulose, .5% binder)
PBXN-5	Navy PBX formulation (95% HMX, 5% fluoroelastomer)
PBXN-301	Navy insensitive explosive formulation
PEO Ammo	Program Executive Officer Ammunition
PETN	Pentaerythritol tetranitrate
PIC	Precision Initiation Couplers
RCMP	Range Complex Management Plan
RDT&E	Research, development, test, and evaluation
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
REVA	Range Environmental Vulnerability Assessment
RF	Radio Frequency
RSEPA	Range Sustainability Environmental Program Assessment
RTLP	Range and Training Land Program
S&A	Safing and Arming
SDWA	Safe Drinking Water Act
SERDP	Strategic Environmental Research and Development Program
SOP	Standard Operation Procedure
SPC	Statistical Process Control
SRP	Sustainable Range Program
SRPP	Sustainable Range Program Plan
TAP	Tactical Training Theater Assessment and Planning
TNAZ	1,3,3-trinitroazetidine
TNT	2,4,6-Trinitrotoluene
TPE	Thermoplastic Elastomer
USACE	U.S. Army Corps of Engineers
USD	Under Secretary of Defense
UXO	Unexploded Ordnance

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